State of California
The Resources Agency
Department of Water Resources

SP-G2: EFFECTS OF PROJECT OPERATIONS ON GEOMORPHIC PROCESSES DOWNSTREAM OF OROVILLE DAM

TASK 2 – SPAWNING RIFFLE CHARACTERISTICS

Oroville Facilities Relicensing
FERC Project No. 2100

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SUMMARY

This SP-G2 Task 2 Report "*Spawning Riffle Characteristics*" includes the methodology, results, and conclusions of a Chinook salmon spawning riffle quality evaluation. The riffle sampling and testing was performed by the Department of Water Resources (DWR), Northern District Geology staff during the fall of 2002 and 2003. Riffle sampling data collected included surface and subsurface bed material, temperature, permeability, and dissolved oxygen. Riffles were sampled in the lower Feather River between Oroville and Honcut Creek.

The appendix includes the field data sheets. Data analysis, results, conclusions and recommendations are provided in the main report. The specific locations of gravel sampling are provided in Task 2 - Appendix B "*Atlas of Riffles, Redds and Sampling Locations*", published under separate cover. The location of riffle areas are plotted on the Task 1.2 Atlas and in the DWR-ND geographic information system.

Work under this task included the re-sampling of gravel at the heads of spawning riffles. Riffles were previously sampled in 1982 and 1996. Both bulk sampling and Wolman surface sampling methodology were employed. Bulk samples were separated into a surface sample and a subsurface sample, and analyzed separately.

Riffle shape and area has changed since last surveyed in 1982. Some riffles have moved. Great Western riffle has been washed out and is now a pool. Aleck riffle was scoured by high flows in 1997 and is substantially different from 1982.

An armored layer has developed. The armor layer's Geometric Mean Diameter (Dg) ranges on average from about three to five times the Dg of the subsurface layer. There is a general fining trend in both the surface and subsurface samples in the downstream direction. There is also a temporal coarsening trend, with 2002-03 samples substantially coarser than 1982 samples. The surface layer in some places is too coarse for salmon to successfully spawn in.

The subsurface Dg is much smaller overall. There is a fining trend from the top to the bottom of the study reach. The Dg averages about 20 mm (0.8 in) for the Low Flow Reach and the upper five miles of the High Flow Reach. Spawning gravel criteria based on Dg suggest that, on the average, the samples meet spawning gravel quality criteria. Some of the subsurface samples have Dg that are smaller than ideal spawning gravel. The spawning process, however, removes some of the finer particle fractions.

Bulk sampling of spawning riffle dune and trough structures show that the troughs are generally coarser. The dune-trough structures are probably the result of salmon spawning. The trough is the excavated part of the nest and the dune is the tailspill.

Wolman surface samples were taken near the bulk sample locations. The Wolman

samples consist of measuring 100 particle diameters over a grid and determining the grain size distribution. Wolman samples are faster and simpler than bulk samples. Statistical parameters of Wolman and bulk surface samples were found to be comparable. No attempt was made to compare Wolman samples with bulk subsurface sampling because of the large degree of armoring present.

The Department of Fish and Game (DFG) considers spawning gravel with more than 30 percent cobbles and boulders to be too coarse for salmon spawning. Wolman and bulk surface samples suggest that some riffles exceed this criterion, particularly in the Low Flow Reach in the five miles below the Fish Barrier Dam.

Adequate dissolved oxygen and intragravel flow, as well as proper intragravel temperature, are also required for successful egg survival and emergence. These three parameters were measured in existing salmon redds. Water velocities and water temperature were also measured directly above the redd.

Results of this testing showed that intragravel temperature and water temperature are nearly equal and generally within one-tenth of a degree C. Dissolved oxygen levels were generally high, and does not appear to be a limiting factor. Diurnal sampling at Auditorium riffle in September 2003 suggests that only minor changes in DO and temperature occur during a 24 hour period

Permeabilities were measured at intervals of 6, 12, and 18 inches. Permeabilities were generally high in the top 12 inches. Redds in the Feather generally are not excavated deeper than this. The significantly lower permeabilities measured below 12 inches represent unspawned riffle permeability.

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1.0 INTRODUCTION

Study PlanG2 was designed to evaluate Feather River geomorphic changes resulting from the construction of Oroville Dam. The study reach begins at the Fish Barrier Dam near Oroville and extends to the mouth of the Feather River at Verona, a river distance of about 70 miles. The study plan investigates the hydraulic, geomorphic, and sediment transport changes that have occurred. The effect of these changes on salmonid spawning riffles, flooding, riparian vegetation, riparian habitat, and river habitat was also considered.

Changes in sediment transport were evaluated by use of a sediment transport model. This model will also be used to predict changes in sediment transport and channel meandering resulting from various proposed flow regimes. Based on the results of the study, we will identify needs for protection, mitigation or enhancement activities. The study results will also be used by other studies to help assess and predict the Oroville Facilities ongoing effects over the next 25 and 50 years on downstream water quality, aquatic and riparian resources, and protection of private lands and public trust resources.

This report, *Task 2 – Spawning Riffle Characteristics* is one of a number of reports that fulfill the scope of Study Plan G2. Task 2 presents the results of bulk sampling and Wolman surface sampling on Feather River spawning riffles. Included are Appendix A, with data sheets, and Appendix B, a river atlas showing the location of riffles and sample points.

1.1 BACKGROUND INFORMATION

The Feather River is an important resource for salmonid spawning habitat in California, second only to the Sacramento River. The completion of Oroville Dam in 1967 reduced this habitat by blocking access to upstream reaches. This includes 25 miles to Miocene Dam on the West Branch, 21 miles to Poe Powerhouse on the North Fork, 19 miles to Curtain Falls on the Middle Fork, and 8 miles to Ponderosa Dam on the South Fork. This loss of spawning habitat was mitigated by the Feather River Fish Hatchery. The Hatchery provides an artificial spawning and rearing facility for Chinook salmon and steelhead.

Oroville Dam also affects hydrology and sediment transport characteristics, altering the movement of water, sediment, and woody debris in the river. The primary function of the dam is to store winter and spring runoff for release into the river as necessary for project purposes. This results in an altered hydrologic regime that includes changes to the yearly, monthly, and daily stream flow distributions; bankfull discharge, flow exceedance, peak flow, and other hydraulic characteristics.

The reservoir, along with other hydroelectric projects on the Feather River, also captures most of the sediment eroded from the upper Feather River watershed. This changes patterns of sediment transport and deposition, scour, mobilization of sediment, and levels of turbidity. These changes can result in the coarsening of spawning gravel on riffles, which in turn may adversely affect salmon and steelhead.

These changes to the river hydrology and sedimentation patterns will in turn alter the channel morphology. These can include changes to the channel shape, meandering, and capacity.

These potential impacts may extend downriver from Oroville Dam to the junction with the Sacramento River or beyond. These are further complicated by a long history of a variety of land uses along the Feather River including hydraulic mining, gravel mining, gold dredging, timber harvesting, water diversions, and urbanization.

1.1.1 Study Area

The Lower Feather River flows about 72 miles from Oroville Dam to the Sacramento River at Verona. The river flows past distinctive geographic and geomorphic features. These are shown in Table 1.1-1.

Table 1. 1-1 River Miles, Valley Miles and Related Geographic Features of the Feather River

RIVER MILE (1997 USACE)	RIVER MILE (USGS)	VALLEY MILE	GEOGRAPHIC FEATURE
71.5			Oroville Dam
67.2	67.8		Thermalito Diversion Dam
66.5	67.2		Fish Barrier Dam
66.3	67.0		Table Mountain Bridge
65.0	65.6		Highway 70 Bridge
58.7	59.0		Confluence with Thermalito Afterbay Outflow
50.6	50.8		Gridley Bridge
44.3	44.0		Confluence with Honcut Creek
42.5	42.3		Live Oak
27.9	28.5	24.9	Yuba City and Marysville
27.1	27.5	24.4	Confluence with Yuba River
N/A	25.4	22.6	Upstream End of State Cutoff (1909)
N/A	22.5	20	Downstream End of State Cutoff (1909)
N/A	19.5	17.4	Abbot Lake

RIVER MILE (1997 USACE)	RIVER MILE (USGS)	VALLEY MILE	GEOGRAPHIC FEATURE
N/A	18.8	16.7	Star Bend
N/A	17.0	15.7	O'Conner Lakes
N/A	13.0	12.3	Lake of the Woods
N/A	12.5	11.6	Confluence with Bear River
N/A	9.6	9.1	Town of Nicolaus
N/A	9.3	8.9	99 Bridge (Garden Highway)
N/A	8.2	8	Upstream End of State Cutoff (post-1911)
N/A	7.5	7.3	Confluence with Sutter Bypass; Downstream End State Cutoff (post-1911)
0.0	0.0	0	Verona, Confluence with Sacramento River

More effort was spent on the 39-mile reach from the Fish Barrier Dam to Yuba City (Figure 1.1-1). Below Yuba City, the Yuba and Bear Rivers join the Feather, and the overall effect of Oroville Dam is reduced and obscured. The study boundary extends laterally to the edge of the 500-year floodplain as defined by the USACE (1997).

The study reach is further divided into four subreaches based on differences in the hydrologic flow regime. The first (the Low Flow Reach) is the 8-mile stretch between the Fish Barrier Dam and the Thermalito Afterbay outflow. The second is the 39-mile reach between the Afterbay outflow and the Yuba River. The third is 15 miles from the confluence of the Yuba River to the confluence of the Bear. The fourth, about 12 miles long, begins at the confluence with the Bear and ends at the confluence of the Feather and the Sacramento River at Verona.

Most of the SP-G2 study effort was on the salmon spawning reach between the Fish Barrier Dam and Honcut Creek. The activities included in this reach are: FLUVIAL-12 modeling, sediment sampling, permeability, dissolved oxygen, and temperature measurements. Below Honcut Creek, geomorphic and mesohabitat typing was done, including bank erosion, bank composition, habitat, geology, soils and woody debris.

1.1.2 Description

The Feather River watershed is mainly in the northern Sierra Nevada geomorphic province. The river drains the western slope of the Sierra Nevada and is tributary to the Sacramento River. Some of the headwaters also lie within the Basin and Range geomorphic province, containing both steep forested mountains and large intermountain valleys. The climate is Mediterranean, with mostly dry summers and wet winters. Annual precipitation ranges from 75 inches in the upper watershed to 30 inches in the lower watershed near Oroville Dam.

The Feather River is underlain by resistant metamorphic, volcanic, and plutonic rocks in the 4-mile reach downriver of Oroville Dam to the Fish Diversion Dam. It is incised into these rocks, forming steep canyon walls.

Below the town of Oroville, the Feather River emerges from the Sierra Nevada into the foothills of the Sacramento Valley. At about three quarters of a mile below the Diversion Dam, at the first major spawning riffle, bedrock is still exposed in the channel. Below Bedrock Park, the river begins to flow in an alluvial channel incised into dissected older alluvial uplands.

The Oroville Wildlife Area, consisting of dredger tailings and borrow pits, occurs from a few miles below Oroville to a few miles above Gridley. Below the dredger tailings, the river meanders through hydraulic mining debris, floodplain deposits, and older terrace deposits.

1.1.3 River Acces

The river is accessible by vehicle through the Oroville Wildlife Area and public parks. Numerous public boat ramps are also available. Jet boats can often be used in the High Flow Reach and sometimes in the Low Flow Reach dependent on flow. Seasonal variations in flow can make some riffles difficult or impossible to navigate and submerged snags can be an additional hazard.

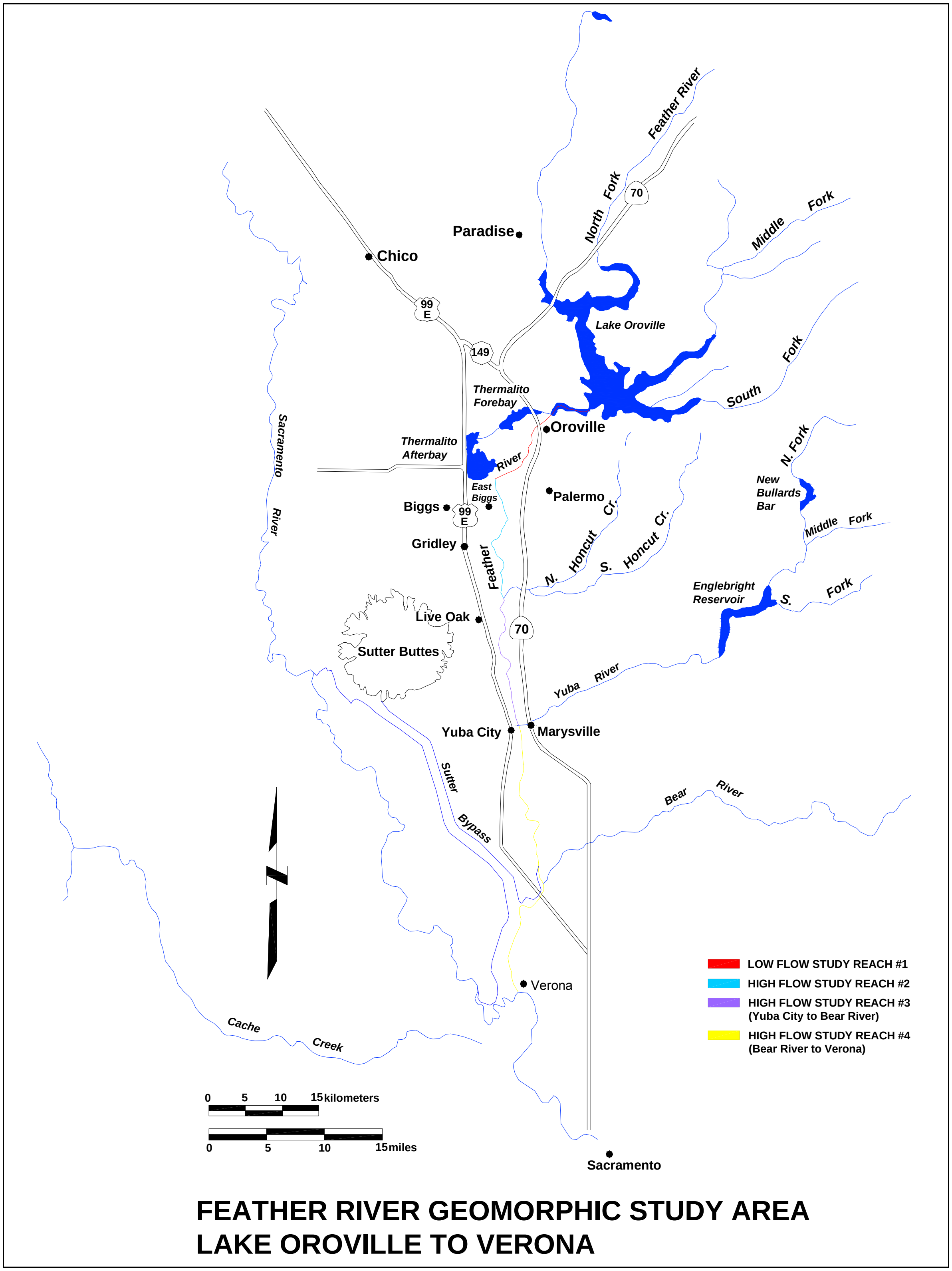


Figure 1.1-1 SP-G2 Geomorphic Study Area and Subreaches, Lake Oroville to Yuba City

1.2 DESCRIPTION OF FACILITIES

The Oroville Facilities were developed as part of the State Water Project (SWP), a water storage and delivery system of reservoirs, aqueducts, power plants, and pumping plants. The main purpose of the SWP is to store and distribute water to supplement the needs of urban and agricultural water users in northern California, the San Francisco Bay area, the San Joaquin Valley, and southern California. The Oroville Facilities are also operated for flood management, power generation, to improve water quality in the Delta, provide recreation, and enhance fish and wildlife.

FERC Project No. 2100 encompasses 41,100 acres and includes Oroville Dam and Reservoir, three power plants (Hyatt Pumping-Generating Plant, Thermalito Diversion Dam Power Plant, and Thermalito Pumping-Generating Plant), Thermalito Diversion Dam, the Feather River Fish Hatchery and Fish Barrier Dam, Thermalito Power Canal, Oroville Wildlife Area (OWA), Thermalito Forebay and Forebay Dam, Thermalito Afterbay and Afterbay Dam, and transmission lines, as well as a number of recreational facilities. Figure 1.2-1 shows an overview of these facilities and the FERC Project boundary. Oroville Dam, along with two small saddle dams, impounds Lake Oroville, a 3.5-million-acre-feet (maf) capacity storage reservoir with a surface area of 15,810 acres at its normal maximum operating level.

The hydroelectric facilities have a combined licensed generating capacity of approximately 762 megawatts (MW). The Hyatt Pumping-Generating Plant is the largest of the three power plants with a capacity of 645 MW. Water from the six-unit underground power plant (three conventional generating and three pumping-generating units) is discharged through two tunnels into the Feather River just downstream of Oroville Dam. The plant has a generating and pumping flow capacity of 16,950 cfs and 5,610 cfs, respectively. Other generation facilities include the 3-MW Thermalito Diversion Dam Power Plant and the 114-MW Thermalito Pumping-Generating Plant.

Thermalito Diversion Dam four miles downstream of the Oroville Dam creates a tail water pool for the Hyatt Pumping-Generating Plant and is used to divert water to the Thermalito Power Canal. The Thermalito Diversion Dam Power Plant is a 3-MW power plant located on the left abutment of the Diversion Dam. The power plant releases a maximum of 615 cubic feet per second (cfs) of water into the river.

The Power Canal is a 10,000-foot-long channel designed to convey generating flows of 16,900 cfs to the Thermalito Forebay and pump-back flows to the Hyatt Pumping-Generating Plant. The Thermalito Forebay is an off-stream regulating reservoir for the 114-MW Thermalito Pumping-Generating Plant. The Thermalito Pumping-Generating Plant is designed to operate in tandem with the Hyatt Pumping-Generating Plant and has generating and pump-back flow capacities of 17,400 cfs and 9,120 cfs, respectively. When in generating mode, the Thermalito Pumping-Generating Plant discharges into

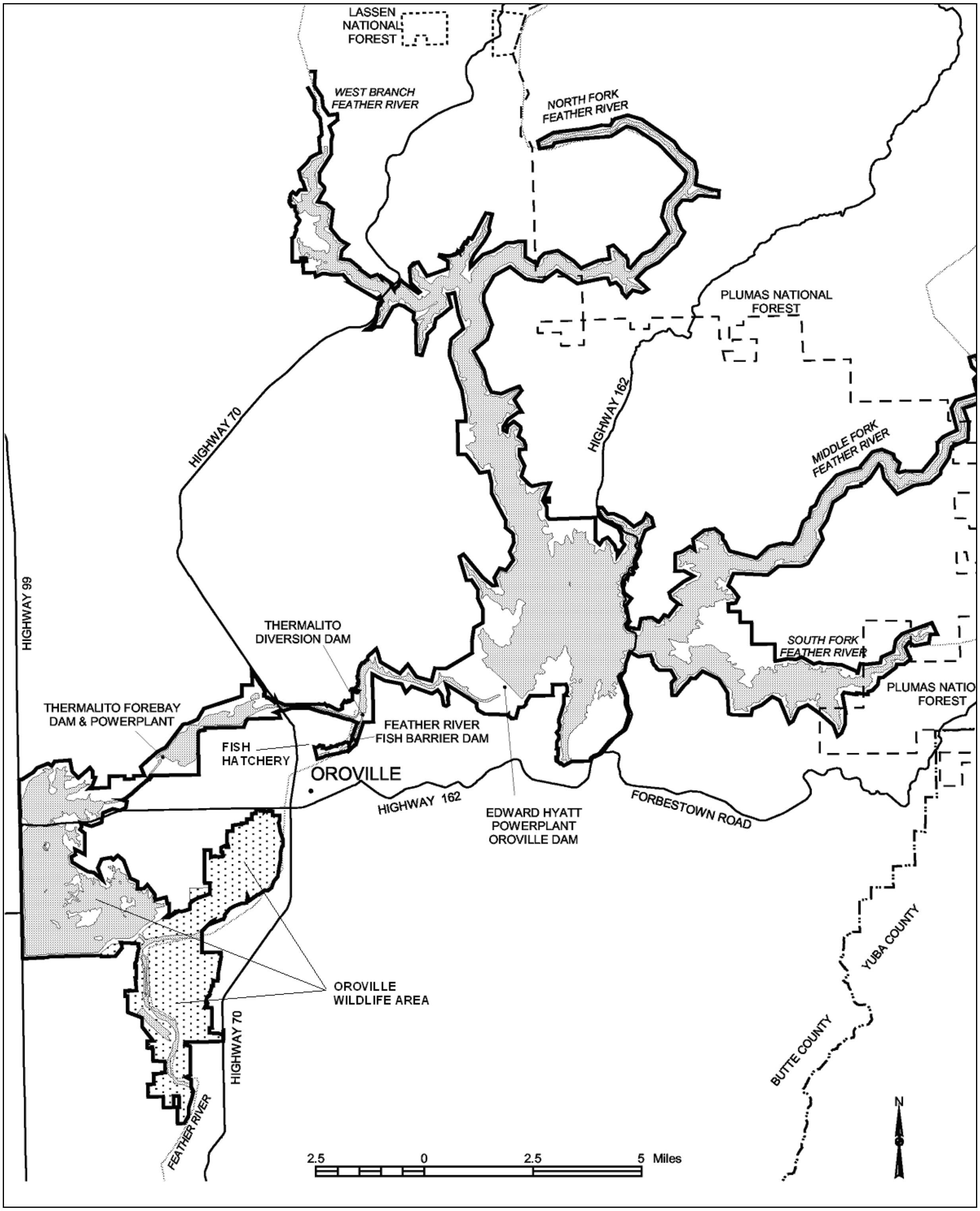


Figure 1.2-1. Overview of FERC Project No. 2100 Facilities.

the Thermalito Afterbay, which is contained by a 42,000-foot-long earth-fill dam. The Afterbay is used to release water into the Feather River downstream of the Oroville Facilities, helps regulate the power system, provides storage for pump-back operations, and provides recreational opportunities. Several local irrigation districts receive water from the Afterbay.

The Feather River Fish Barrier Dam is downstream of the Thermalito Diversion Dam and immediately upstream of the Feather River Fish Hatchery. The flow over the dam maintains fish habitat in the low-flow channel of the Feather River between the dam and the Afterbay outlet, and provides attraction flow for the hatchery. The hatchery was intended to compensate for spawning grounds lost to returning salmon and steelhead trout from the construction of Oroville Dam. The hatchery can accommodate 15,000 to 20,000 adult fish annually.

The Oroville Facilities support a wide variety of recreational opportunities. They include: boating (several types), fishing (several types), fully developed and primitive camping (including boat-in and floating sites), picnicking, swimming, horseback riding, hiking, off-road bicycle riding, wildlife watching, hunting, and visitor information sites with cultural and informational displays about the developed facilities and the natural environment. There are major recreation facilities at Loafer Creek, Bidwell Canyon, the Spillway, North and South Thermalito Forebay, and Lime Saddle. Lake Oroville has two full-service marinas, five car-top boat launch ramps, ten floating campsites, and seven dispersed floating toilets. There are also recreation facilities at the Visitor Center and the OWA.

The OWA comprises approximately 11,000-acres west of Oroville that is managed for wildlife habitat and recreational activities. It includes the Thermalito Afterbay and surrounding lands (approximately 6,000 acres) along with 5,000 acres adjoining the Feather River. The 5,000 acre area straddles 12 miles of the Feather River, which includes willow and cottonwood lined ponds, islands, and channels. Recreation areas include dispersed recreation (hunting, fishing, and bird watching), plus recreation at developed sites, including Monument Hill day use area, model airplane grounds, three boat launches on the Afterbay and two on the river, and two primitive camping areas. California Department of Fish and Game’s (DFG) habitat enhancement program includes a wood duck nest-box program and dry land farming for nesting cover and improved wildlife forage. Limited gravel extraction also occurs in a number of locations.

1.3 CURRENT OPERATIONAL CONSTRAINTS

Operation of the Oroville Facilities varies seasonally, weekly and hourly, depending on hydrology and the objectives DWR is trying to meet. Typically, releases to the Feather River are managed to conserve water while meeting a variety of water delivery requirements, including flow, temperature, fisheries, recreation, diversion and water quality. Lake Oroville stores winter and spring runoff for release to the Feather River as necessary for project purposes. Meeting the water supply objectives of the SWP has always been the primary consideration for determining Oroville Facilities operation (within the regulatory constraints specified for flood control, in-stream fisheries, and downstream uses). Power production is scheduled within the boundaries specified by the water operations criteria noted above. Annual operations planning are conducted for multi-year carry over. The current methodology is to retain half of the Lake Oroville storage above a specific level for subsequent years. Currently, that level has been established at 1,000,000 acre-feet (af); however, this does not limit draw down of the reservoir below that level. If hydrologic conditions are drier than expected or water requirements greater than expected, additional water would be released from Lake Oroville. The operations plan is updated regularly to reflect changes in hydrology and downstream operations. Typically, Lake Oroville is filled to its maximum annual level of up to 900 feet above mean sea level (msl) in June and then can be lowered as necessary to meet downstream requirements, to its minimum level in December or January. During drier years, the lake may be drawn down more and may not fill to the desired levels the following spring. Project operations are directly constrained by downstream operational constraints and flood management criteria as described below.

1.3.1 Downstream Operation

An August 1983 agreement between DWR and DFG entitled, “Agreement Concerning the Operation of the Oroville Division of the State Water Project for Management of Fish & Wildlife,” sets criteria and objectives for flow and temperatures in the low flow channel and the reach of the Feather River between Thermalito Afterbay and Verona. This agreement: (1) establishes minimum flows between Thermalito Afterbay Outlet and Verona which vary by water year type; (2) requires flow changes under 2,500 cfs to be reduced by no more than 200 cfs during any 24-hour period, except for flood management, failures, etc.; (3) requires flow stability during the peak of the fall-run Chinook spawning season; and (4) sets an objective of suitable temperature conditions during the fall months for salmon and during the later spring/summer for shad and striped bass.

1.3.1.1 Instream Flow Requirements

The Oroville Facilities are operated to meet minimum flows in the Lower Feather River as established by the 1983 agreement (see above). The agreement specifies that Oroville Facilities release a minimum of 600 cfs into the Feather River from the Thermalito Diversion Dam for fisheries purposes. This is the total volume of flows from the diversion dam outlet, diversion dam power plant, and the Feather River Fish Hatchery pipeline.

Generally, the instream flow requirements below Thermalito Afterbay are 1,700 cfs from October through March, and 1,000 cfs from April through September. However, if runoff for the previous April through July period is less than 1,942,000 af (i.e., the 1911-1960 mean unimpaired runoff near Oroville), the minimum flow can be reduced to 1,200 cfs from October to February, and 1,000 cfs for March. A maximum flow of 2,500 cfs is maintained from October 15 through November 30 to prevent spawning in overbank areas that might become de-watered.

1.3.1.2 Temperature Requirements

The Diversion Pool provides the water supply for the Feather River Fish Hatchery. The hatchery objectives are 52°F for September, 51°F for October and November, 55°F for December through March, 51°F for April through May 15, 55°F for last half of May, 56°F for June 1-15, 60°F for June 16 through August 15, and 58°F for August 16-31. A temperature range of plus or minus 4°F is allowed for objectives, April through November.

There are several temperature objectives for the Feather River downstream of the Afterbay Outlet. During the fall months, after September 15, the temperatures must be suitable for fall-run Chinook. From May through August, they must be suitable for shad, striped bass, and other warmwater fish.

The National Marine Fisheries Service has also established an explicit criterion for steelhead trout and spring-run Chinook salmon. Memorialized in a biological opinion on the effects of the Central Valley Project and SWP on Central Valley spring-run Chinook and steelhead as a reasonable and prudent measure; DWR is required to control water temperature at Feather River mile 61.6 (Robinson's Riffle in the low-flow channel) from June 1 through September 30. This measure requires water temperatures less than or equal to 65°F on a daily average. The requirement is not intended to preclude pump-back operations at the Oroville Facilities needed to assist the State of California with supplying energy during periods when the California ISO anticipates a Stage 2 or higher alert.

The hatchery and river water temperature objectives sometimes conflict with temperatures desired by agricultural diverters. Under existing agreements, DWR provides water for the Feather River Service Area (FRSA) contractors. The contractors claim a need for warmer water during spring and summer for rice germination and growth (i.e., 65°F from approximately April through mid May, and 59°F during the remainder of the growing season). There is no obligation for DWR to meet the rice water temperature goals. However, to the extent practical, DWR does use its operational flexibility to accommodate the FRSA contractor's temperature goals.

1.3.1.3 Water Diversions

Monthly irrigation diversions of up to 190,000 (July 2002) acre-feet are made from the Thermalito Complex during the May through August irrigation season. Total annual entitlement of the Butte and Sutter County agricultural users is approximately 1 maf.

After meeting these local demands, flows into the lower Feather River continue into the Sacramento River and into the Sacramento-San Joaquin Delta. In the northwestern portion of the Delta, water is pumped into the North Bay Aqueduct. In the south Delta, water is diverted into Clifton Court Forebay where the water is stored until it is pumped into the California Aqueduct.

1.3.1.4 Water Quality

Flows through the Delta are maintained to meet Bay-Delta water quality standards arising from DWR's water rights permits. These standards are designed to meet several water quality objectives such as salinity, Delta outflow, river flows, and export limits. The purpose of these objectives is to attain the highest water quality, which is reasonable, considering all demands being made on the Bay-Delta waters. In particular, they protect a wide range of fish and wildlife including Chinook salmon, Delta smelt, striped bass, and the habitat of estuarine-dependent species.

1.3.2 Flood Management

The Oroville Facilities are an integral component of the flood management system for the Sacramento Valley. During the wintertime, the Oroville Facilities are operated under flood control requirements specified by the U.S. Army Corps of Engineers (USACE). Under these requirements, Lake Oroville is operated to maintain up to 750,000 acre-feet of storage space to allow for the capture of significant inflows. Flood control releases are based on the release schedule in the flood control diagram or the emergency spillway release diagram prepared by the USACE, whichever requires the greater release. Decisions regarding such releases are made in consultation with the USACE.

The flood control requirements are designed for multiple use of reservoir space. During times when flood management space is not required to accomplish flood management objectives, the reservoir space can be used for storing water. From October through March, the maximum allowable storage limit (point at which specific flood release would have to be made) varies from about 2.8 to 3.2 maf to ensure adequate space in Lake Oroville to handle flood flows. The actual encroachment demarcation is based on a wetness index, computed from accumulated basin precipitation. This allows higher levels in the reservoir when the prevailing hydrology is dry while maintaining adequate flood protection. When the wetness index is high in the basin (i.e., wetness in the watershed above Lake Oroville), the flood management space required is at its greatest amount to provide the necessary flood protection. From April through June, the maximum allowable storage limit is increased as the flooding potential decreases, which allows capture of the higher spring flows for use later in the year. During September, the maximum allowable storage decreases again to prepare for the next flood season. During flood events, actual storage may encroach into the flood reservation zone to prevent or minimize downstream flooding along the Feather River.

2.0 NEED FOR STUDY

A naturally functioning channel in dynamic equilibrium is capable of transporting the water and sediment delivered to it without significantly changing its geometry, streambed composition, or gradient through time. The flow conditions that promote this stability can be described as geomorphically significant flows (bankfull). These flows do the majority of the sediment transport and are considered most responsible for channel form. A natural flow regime typically includes flow ranges responsible for in-channel clearing and overbank flows to support riparian vegetation, along with channel-forming flows.

Project -related structures and operations also alter flow regimes, which can impact the occurrence of geomorphically significant flows. Potential adverse effects include loss of undercut banks, increased fine sediment from loss of flushing flows, loss of channel capacity, reduced sediment transport capability, channel scour, armoring, and impairment of the ability of the stream to maintain functional riparian and instream habitat.

2.1 PURPOSE AND SCOPE

The altered sediment routing and hydrology caused by the Oroville Facilities have affected Feather River morphology below the dam. This geomorphic investigation compares historic and current conditions to help identify ongoing project effects to the downstream reaches. It will be used by other studies to help assess the project's effects on plant, fish, animal, and riparian resources caused by hydrologic, channel, and sediment routing changes. There is a need to understand these relationships and identify potential protection, mitigation and enhancement measures (PM&Es).

The purpose of Task 2 is to assess changes in chinook spawning gravel quality in the Lower Feather River. Chinook salmon are anadromous, which means most of the life cycle is spent in the ocean. The salmon migrate up the Feather and other rivers when ready to spawn. Salmon dig nests, or redds, in the river gravel. Eggs are spawned, fertilized, and buried in the gravel. After an incubation period of about 60 days, the eggs hatch and the young emerge. The young migrate to the sea and return in two to five years to repeat the cycle.

The two main runs of salmon occur in the fall and spring. The fall-run is the largest. The adults enter the river and spawn between October and early December. Outmigration of the young peaks in March and April and is completed in June. Spring-run salmon arrive between March and June and spawn from late September to mid-October. The spawning overlaps fall-run spawning.

Other anadromous species include steelhead, American shad, and striped bass. These and various resident fish spawning habitat requirements were not considered in this study. It is expected that overall maintenance and enhancement of river habitat for chinook will also improve habitat for other species.

3.0 STUDY OBJECTIVE(S)

3.1 APPLICATION OF STUDY INFORMATION

The objective is to determine the ongoing effects of altered downstream hydrology and sediment retention in Lake Oroville on channel morphology and sediment transport below Lake Oroville.

The study will determine the ongoing Oroville Project effects on river flows and morphology downstream of Oroville Dam. Specifically, the study will address the following components:

1. Determine sediment conditions and sediment transport requirements.
2. Evaluate sediment sources (including tributaries) and conditions.
3. Map major sediment deposits.
4. Evaluate stream channel stability.
5. Evaluate project-affected sediment regimes.
6. Evaluate timing, magnitude, and duration of project-affected flows in relation to geomorphic effects and spawning habitat.
7. Determine the effect of the project on fluvial geomorphologic features.
8. Evaluate erosional effects on farmland and public trust resources.

This Task 2 report evaluates Chinook salmon spawning gravel in the Lower Feather River. Study results will be used to identify limiting factors and biological effects. The information could be used to develop a comprehensive spawning gravel management plan to improve spawning gravel quality in the Feather River. The study results could also be used by other studies to help assess the Oroville Facilities ongoing effects on biologic and public trust resources.

3.1.2 Other Studies

Studies related to spawning gravel quantity and quality began before construction of Oroville Dam. DWR (1965) studied pre-dam channel characteristics, and then DWR (1969) and the USGS (1972) conducted studies to document channel changes. In 1977 DF&G studied the interim impacts of the dam on salmonid escapement. In 1978 the USGS did another study to evaluate sediment transport and discharge. Because of the findings of several of the previous investigations, DWR (1982) prepared the Feather River Spawning Gravel Baseline Study to determine the condition of spawning gravel in the upper Feather River. The report identified factors resulting in the reduction of spawning gravel quality. These include the loss of gravel recruitment from areas above Oroville Dam and the effect of scouring flood flows. A follow-up habitat restoration project was conducted by DWR and DF&G in 1982 at the riffle sites adjacent to the Hatchery. These sites were identified in the baseline study as having undergone significant post-dam degradation.

Surface and bulk gravel sampling for the 1982 study showed that riffles in the river between the Oroville Fish Hatchery and the Highway 70 Bridge are paved by cobbles. The degree of armoring diminishes downstream. Below the Highway 162 Bridge the armoring effect diminishes rapidly and the gravel in riffles is generally appropriate for salmon spawning.

In the 1982 study, surface samples were taken on point bars and the size distribution, median, first and second standard deviation, skewness and kurtosis calculated. One hundred and seventy six surface samples were taken between the Fish Barrier Dam and Honcut Creek. Bulk samples were taken on 18 point bars.

Although the study concluded that in-channel enhancement projects would run a high risk of failure because of high velocities, lack of recruitment, and short flood recurrence intervals, it also proposed a comprehensive management and monitoring program that included restoration, gravel augmentation, and enhancement of habit.

DWR sampled key riffles again in 1996 to document changes in spawning gravel quality.

4.0 STUDY ORGANIZATION

4.1 STUDY DESIGN

The original seven individual tasks and sub-tasks specified in the study plan have been re-organized into the following:

- Task 1.1 - obtain, review, and summarize existing resource data and references;
- Task 1.2 – prepare a general description of the lower Feather River and watershed;
- Task 2 - map and characterize spawning riffles;
- Task 3 and 4 - evaluate changes to the channel morphology by re-establishing historic cross-section surveys and photo points;
- Task 6 - assess current channel characteristics and monitor selected cross-sections for significant changes to those characteristics; establish bank erosion monitoring sites
- Task 5 and 8 - determine project effects on river hydraulic and geomorphic parameters;
- Task 7 - model sediment transport and channel hydraulics; make predictions

Each of these bulleted items are published as a separate report. This specific report is organized by and fulfills the requirements for “Task 2 – Spawning Riffle Characteristics”.

4.2 HOW AND WHERE THE STUDIES WERE CONDUCTED

DWR Northern District – Geologic Investigations Section staff conducted office and field work to meet the requirements of the SP-G2 study plan. Office work focused on researching and collecting references and data sets, performing sieve analyses of sediment samples, documenting field surveys, and preparation of maps, charts, and figures. Some of the gravel sampling work was geared to providing data for development of the Fluvial-12 sediment transport model. Field work concentrated on finding and re-surveying historic cross-sections, collecting bulk and sediment samples, and classifying river habitat. Most of the work was done in the chinook salmon spawning reach between the Fish Barrier Dam and the Feather River confluence with Honcut Creek.

5.0 GRAVEL SAMPLING OF SPAWNING RIFFLES

The Feather River has historically been second only to the Sacramento River for the quality and quantity of Chinook salmon spawning habitat in the Sacramento River. Since closure of Oroville Dam in 1967, natural spawning only occurs on riffles below the dam. Loss of spawning area above the dam was mitigated for by the Feather River Hatchery.

The two most important spawning gravel characteristics are the particle size distribution and the permeability. Salmonids require gravel within a specific size range, depending on species, fish size, and egg size. Cobbles that are too large for the salmon to move are detrimental to successful spawning. Excess fine materials in the interstices reduce egg and fry survival by reducing the permeability and gravel escapement.

There are about 20 major spawning riffles on the Feather River between the Fish Barrier Dam and Honcut Creek. Below Honcut, the substrate becomes too fine for successful spawning. Other environmental conditions, such as water temperature, are also limiting.

5.1 SITE SELECTION

Sites for sampling were selected based on the location of previous sampling. The Northern District bulk and surface sampled twenty riffles between Oroville and Honcut Creek as part of the 1982 "*Feather River Spawning Gravel Baseline Study*". The Hatchery and Auditorium Riffles and Moe's Ditch were re-sampled in 1983 as part of the "*Monitoring Spawning Habitat, Feather River, California*" report. The gravel sampling locations were sampled again in 1996 and 1997 at the request of DWR's Environmental Services Office. Finally these locations were again sampled between October 2002 and May 2003 as part of this study in support of the FERC relicensing of Oroville Dam.

In 1982 DWR selected gravel sampling locations at the head of point bars (Figure 1).

The head, or upstream end of a point bar, was selected for several reasons. First, the same geomorphic area within the river was consistently sampled so that downstream trends in grain size would be apparent. Second, the most ideal hydrologic conditions for spawning, and therefore most of the spawning, generally occur at the heads of riffles. Third, the gravel size distribution on the riffle is similar to the point bar because both were deposited under the same hydraulic conditions during floods.

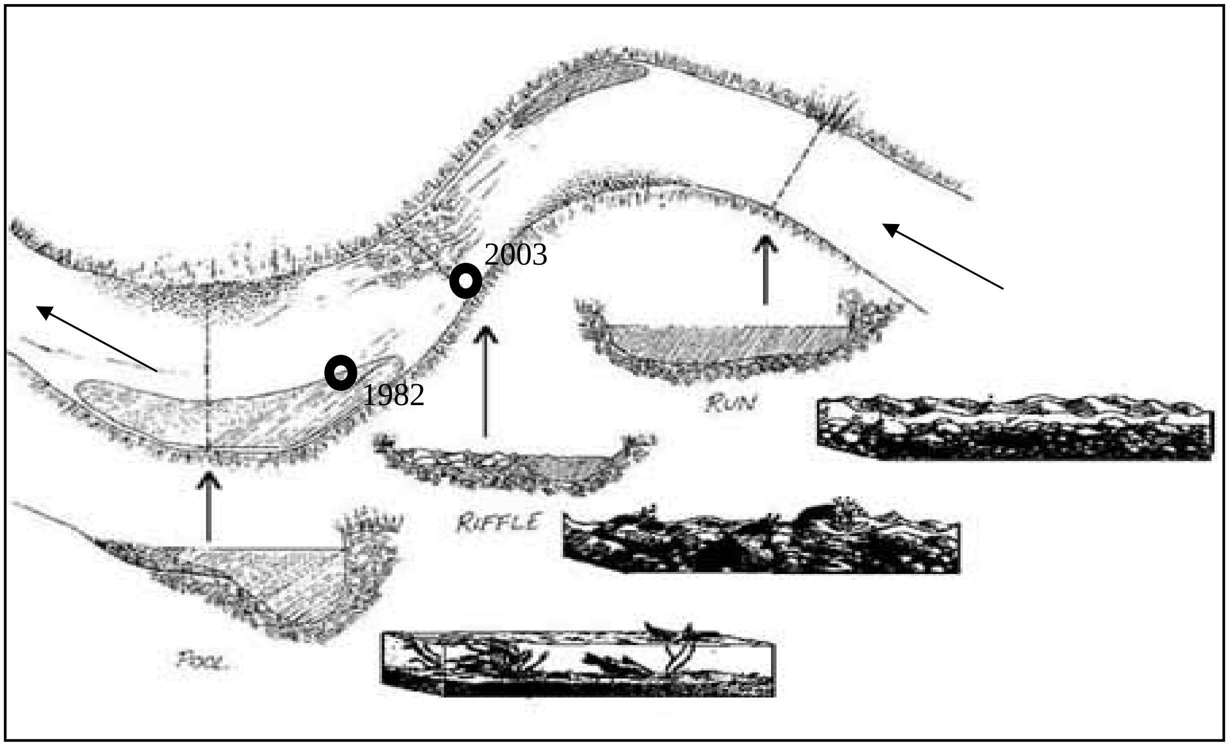


Figure 5.1-1. DWR Bulk Gravel Sampling Locations in 1982 and 2003

Finer deposits generally occur farther downstream on a point bar and in other places, but these areas are less ideal for spawning.

In 1996, DWR repeated sampling at the same riffles sampled in 1982. However some of the 1996 sites selected varied in location from the 1982 sites because the riffles had washed out or moved downstream because of flood flows.

In 2002 and 2003 sampling locations were selected as follows:

1) DWR's 1982 spawning gravel atlas showing these sample locations was rectified so real world coordinates could be assigned to the sites. First the atlas from the *"Feather River Spawning Gravel Baseline Study"* (DWR 1982) was rectified to match the "master" AutoCad file that supports the SP-G2 Task requirements. The 1981 bulk and Wolman sampling locations were then digitized into the AutoCad atlas.

2) Coordinates of the sampling locations were then compiled into an Excel spreadsheet. The sampling locations were also printed out as a field atlas using a 2001 aerial photograph base. These locations were then located using the GPS along with 1982 River Atlas. The sites were selected to duplicate the same geomorphic feature that

previously been sampled.

3) The 1996 sampling sites were transferred to an AutoCad base map so real world coordinates could be assigned.

4) The sampling locations were identified in the field using the coordinates, GPS, and the field atlas.

5) Additional sampling locations were identified because of a number of factors. First the channel conditions may have changed since 1981. The 1986 (143,000 cfs) and 1997 (150,000 cfs) floods significantly changed the channel geomorphology. This was especially true at the Great Western and Robinson riffles, where the point bars and riffles shifted downstream. The 2003 sampling included both the original geographic location of the sampling site as well as the head of the point bar.

6) The riffles in places displayed alternating dune and trough bedforms transverse to flow. Where visual examination showed a difference in sediment size, both of these regions were sampled.

A total of 64 bulk samples and 219 Wolman counts have been collected to date, as shown in Table 5.1-1.

Table 5.1-1. Lower Feather River Gravel Sampling, Oroville to Honcut Creek.

River Mile (USACE)	Riffle or Feature	Year and # of Samples (B = bulk sample, W =Wolman sample)					
		1981-82	1983	1991*	1996	1997	2002/03
66.98	Table Mountain Bridge	----	----	----	----	----	----
66.54		1W	----	----	----	----	----
66.07	Hatchery Riffle	2W	1W	----	1B,1W	----	1B,2W
	Moe's Ditch	2B, 6W	1B,6W	----	----	----	1B,2W
65.77	Auditorium Riffle	2W	----	----	1B,1W	----	1B,1W

River Mile (USACE)	Riffle or Feature	Year and # of Samples (B = bulk sample, W =Wolman sample)					
		1981-82	1983	1991*	1996	1997	2002/03
65.68	Highway 70 Bridge	----	----	----	----	----	----
65.19	Bedrock Park Riffle	1B,3W	----	----	1B,1W	1W	1B,2W
64.48	Highway 162 Bridge	----	----	----	----	----	----
63.39	Mathews Riffle	1B,5W	----	----	1B,1W	1W	1B,1W
62.81	Aleck Riffle	1B,2W	----	----	1B,1W	1W	2B,2W
		1B,2W	----	----	----	----	----
62.14	Great Western Riffle	----	----	----	----	----	----
		1W	----	----	----	----	1B,1W
61.12	Robinson Riffle	1B,2W	----	----	1B,1W	----	1B,2W
		4W	----	----	----	----	4W
60.66	Steep Riffle	1B,1W	----	----	1B,1W	----	1B,4W
		4W	----	----	----	----	1W
60.43	Weir Riffle	1B,4W	----	----	1B,1W	----	1B,3W
60.08	Eye Riffle	1W	----	----	1B,1W	----	1B,2W
59.46	Gateway Riffle	1B,3W	----	----	1B,1W	1W	1B,1W
		4W	----	----	----	----	----
58.98	Thermalito. Spillway	----	----	----	----	----	----
Low Flow Subtotals:		10B, 47W	1B, 7W	0B, 0W	10B, 10W	0B, 4W	13B, 28W

River Mile (USACE)	Riffle or Feature	Year and # of Samples (B = bulk sample, W =Wolman sample)					
		1981-82	1983	1991*	1996	1997	2002/03
58.98	Thermalito. Spillway	----	----	----	----	----	----
		3W	----	----	----	----	----
58.27	Sutter Butte Riffle	1B,12W	----	----	1B,1W	----	2B,2W
57.47	Big Hole	3W	----	----	----	----	----
57.17	Conveyor Belt Riffle	1B,4W	----	----	1B,1W	----	1B
56.26	Hour Riffle	1B,12W	----	----	1B,1W	----	1B,1W
		3W	----	----	----	----	----
54.70	Keister Riffle	1B,7W	----	1W	1B,1W	----	1B,1W
53.44	Goose Riffle	2B,6W	----	----	1B,1W	----	1B,1W
52.91	Big Riffle	----	----	2W	1B,1W	----	3B,3W
52.01	MacFarland Riffle	1B,10W	----	----	1B,1W	----	1B,1W
50.96	Gridley Highway Bridge	----	----	----	----	----	----
49.25	Gridley Riffle	1B,13W	----	----	1B,1W	----	----
	Junkyard Riffle	11W	----	----	1B,1W	----	1B,2W
		6W	----	----	----	----	----
46.27	Herringer Riffle	6W	----	----	----	----	2B,2W
		5W	----	----	----	----	----
44.66	Honcut Creek	1W	----	----	----	----	----

River Mile (USACE)	Riffle or Feature	Year and # of Samples (B = bulk sample, W =Wolman sample)					
		1981-82	1983	1991*	1996	1997	2002/03
High Flow Subtotals:		8B, 98W	0B, 0W	0B, 3W	9B, 9W	0B, 0W	13B, 13W
OVERALL TOTALS:		18B, 145W	1B, 7W	0B, 3W	19B, 19W	0B, 4W	26B, 41W
* sampled for the USACE (W.E.T., 1991)							

5.1.1 Spawning Riffles

Twenty major spawning riffles occur in the 22 river miles between the Fish Barrier Dam and the Feather River confluence with Honcut Creek. Table 5.1-2 shows the location and area of these riffles. Moes ditch is an artificial side channel and is not shown on this table.

Table 5.1-2. Summary of 2002-03 Spawning Riffle Areas, Lake Oroville to Honcut Creek.

River Mile (USACE) - upstream end	River Mile (USACE) - downstream end	*Location	Riffle Area (feet^2)	Riffle Area (%)	Pool Area (feet^2)	Pool Area (%)	Glide Area (feet^2)	Glide Area (%)	Run Area (feet^2)	Run Area (%)	Backwater Area (feet^2)	Backwater Area (%)	Boulder Run Area (feet^2)	Boulder Run Area (%)	Total Area (feet^2)
71.50	71.50	OROVILLE DAM													
67.13	67.13	THERMALITO DIVERSION DAM													
66.54	66.54	FISH BARRIER DAM													
66.28	66.28	TABLE MOUNTAIN BRIDGE													
66.17	66.01	Hatchery Riffle	166,794	45.9	117,782	32.4	75,232	20.7	0	0.0	3,484	1.0	0	0.0	363,292
65.87	65.67	Auditorium Riffle	127,302	51.7	19,675	8.0	84,200	34.2	0	0.0	15,096	6.1	0	0.0	246,274
65.37	65.12	Bedrock Park Riffle	125,318	37.4	73,124	21.8	123,963	37.0	0	0.0	12,350	3.7	0	0.0	334,755
65.00	65.00	HIGHWAY 70 BRIDGE													
63.87	63.87	HIGHWAY 162 BRIDGE													
63.83	63.35	Mathews Riffle	157,186	25.8	178,198	29.3	208,641	34.3	0	0.0	64,508	10.6	0	0.0	608,532
62.92	62.57	Aleck Riffle	19,635	4.0	385,291	78.7	35,347	7.2	0	0.0	49,285	10.1	0	0.0	489,559
62.34	62.19	Great Western Riffle	0	0.0	245,900	89.1	0	0.0	0	0.0	0	0.0	30,056	10.9	275,956
61.39	61.23	Robinson Riffle (upper)	77,603	18.4	129,218	30.6	208,264	49.3	0	0.0	7,675	1.8	0	0.0	422,761
61.20	60.95	Robinson Riffle (lower)	42,223	28.2	0	0.0	40,659	27.1	33,508	22.4	33,371	22.3	0	0.0	149,760
60.73	60.57	Steep Riffle	72,328	31.4	50,404	21.9	28,881	12.5	0	0.0	78,909	34.2	0	0.0	230,522
60.53	60.25	Weir Riffle	0	0.0	18,638	8.5	0	0.0	192,833	87.5	8,866	4.0	0	0.0	220,336
60.05	59.87	Eye Riffle	31,880	13.3	91,996	38.3	45,268	18.8	0	0.0	71,097	29.6	0	0.0	240,240

River Mile (USACE) - upstream end	River Mile (USACE) - downstream end	*Location	Riffle Area (feet^2)	Riffle Area (%)	Pool Area (feet^2)	Pool Area (%)	Glide Area (feet^2)	Glide Area (%)	Run Area (feet^2)	Run Area (%)	Backwater Area (feet^2)	Backwater Area (%)	Boulder Run Area (feet^2)	Boulder Run Area (%)	Total Area (feet^2)
59.55	59.27	Gateway Riffle	12,364	3.1	61,447	15.6	92,072	23.3	0	0.0	229,193	58.0	0	0.0	395,075
58.72	58.72	THERMALITO SPILLWAY													
		SUBTOTAL:	832,634	20.9	1,371,672	34.5	942,527	23.7	226,340	5.7	573,833	14.4	30,056	0.8	3,977,062
58.48	58.07	Sutter Butte Riffle	181,209	24.4	108,531	14.6	447,628	60.2	0	0.0	6,662	0.9	0	0.0	744,030
57.49	57.39	Big Hole	39,576	18.4	27,445	12.8	141,747	66.0	0	0.0	6,129	2.9	0	0.0	214,896
56.90	56.20	Hour Riffle (upper)	226,757	18.3	13,200	1.1	974,419	78.6	0	0.0	25,741	2.1	0	0.0	1,240,117
56.08	55.50	Hour Riffle (lower)	411,757	42.4	327,736	33.8	190,488	19.6	0	0.0	40,868	4.2	0	0.0	970,848
54.83	54.55	Keister Riffle	151,833	27.0	98,291	17.5	292,279	52.0	0	0.0	19,672	3.5	0	0.0	562,075
54.46	54.20	Goose Riffle	48,018	15.2	191,030	60.6	76,069	24.1	0	0.0	0	0.0	0	0.0	315,117
53.66	52.94	Big Riffle	110,811	10.4	700,378	65.6	197,687	18.5	0	0.0	58,942	5.5	0	0.0	1,067,817
52.37	51.86	MacFarland Riffle (upper)	13,095	2.5	136,842	26.4	242,377	46.7	101,337	19.5	25,104	4.8	0	0.0	518,754
51.64	51.42	MacFarland Riffle (lower)	107,340	31.4	235,022	68.6	0	0.0	0	0.0	0	0.0	0	0.0	342,362
50.55	50.55	GRIDLEY HIGHWAY BRIDGE													
49.40	49.04	Gridley Riffle	58,395	8.3	347,443	49.3	288,000	40.9	0	0.0	10,277	1.5	0	0.0	704,114
48.73	48.38	Junkyard Riffle (upper)	313,841	49.1	179,896	28.1	145,333	22.7	0	0.0	0	0.0	0	0.0	639,069
48.05	47.83	Junkyard Riffle (lower)	92,997	20.0	372,990	80.0	0	0.0	0	0.0	0	0.0	0	0.0	465,987
47.57	47.35	Herringer Riffle (upper)	69,013	20.2	273,190	79.8	0	0.0	0	0.0	0	0.0	0	0.0	342,203
46.50	46.07	Herringer Riffle (lower)	120,880	20.4	305,991	51.5	147,723	24.9	0	0.0	19,227	3.2	0	0.0	593,821

River Mile (USACE) - upstream end	River Mile (USACE) - downstream end	*Location	Riffle Area ($feet^2$)	Riffle Area (%)	Pool Area ($feet^2$)	Pool Area (%)	Glide Area ($feet^2$)	Glide Area (%)	Run Area ($feet^2$)	Run Area (%)	Backwater Area ($feet^2$)	Backwater Area (%)	Boulder Run Area ($feet^2$)	Boulder Run Area (%)	Total Area ($feet^2$)
44.32	44.32	HONCUT CREEK													
		SUBTOTAL:	1,945,521	22.3	3,317,985	38.0	3,143,750	36.0	101,337	1.2	212,619	2.4	0	0.0	8,721,212
		TOTALS:	2,778,155	21.9	4,689,656	36.9	4,086,277	32.2	327,677	2.6	786,453	6.2	30,056	0.2	12,698,274

5.1.1.1 Hatchery Riffle. Hatchery Riffle is the closest to the fish hatchery and is one of the most heavily spawned areas in the study reach. The head of the riffle is formed by an outcrop of resistant metavolcanic bedrock outcrop. Generally salmon spawn along the entire 300 foot- long riffle. The riffle is about 150 feet wide. In 1982, the riffle provided 21,500 square feet of spawning area.

The existing substrate is composed of gravel to cobble-size material. Six foot wide strips of finer gravel have been placed transverse to the streamflow as part of a gravel augmentation project.

This Riffle has remained relatively the same most likely due to bedrock control. The mid- channel bar has been eroded some on the right channel bank and transverse scour channels have developed in several places.

5.1.1.2 Moes Ditch. Moes ditch is an artificial side-channel enhancement site constructed by the California Department of Fish and Game in the 1970s using a bulldozer. The ditch typically attracts many spawners. Spawning gravel has been added to the ditch several times. During the 1970s and 1980s, the ditch was graded on a regular basis because high flows would scour the spawning gravel. Gravel finer that the prevalent grain size typically collected at the bottom of the ditch.

Moes Ditch has changed since 1982. The upper half has widened four fold by eroding into both the mid channel island and the right bank. A cutoff has developed across the mid-channel bar to the left channel in which diverts the majority of the flow to the left channel and a small riffle has developed. The lower reach of Moe's Ditch has turned into a pool due to a small beaver dam at the lower end. The gravel in the lower section has also become imbedded.

5.1.1.3 Auditorium Riffle. This riffle is also heavily spawned also because of its close proximity to the Feather River Hatchery. This riffle is much smaller mostly because of inadequate gradient and low flow velocities over much of the riffle area.

In 1982, the riffle provided 5,200 square feet of spawning area. The substrate is generally adequate for spawning, primarily because of gravel augmentation, although some areas are cobbly and armored.

This Riffle remains relatively unchanged. The mid-channel bar has eroded some increasing the riffle area in this vicinity and a gravel bar has developed at the lower end of Moe's Ditch.

5.1.1.4 Bedrock Park Riffle. Bedrock Park riffle is directly above the Highway 70 bridge. The riffle is long, over 500 feet, and about 150 feet wide. A swimming area is on the left bank and most of the spawning occurs along the center and right bank. The riffle provided about 81,000 square feet of spawning area in 1982. The substrate is predominantly cobbles and coarse gravel. Large cobbles and some boulders occur in places on the riffle surface. There have been no significant changes in the form and layout of this riffle since that time.

5.1.1.5 Mathews Riffle. This riffle, about 1500 feet below the Highway 162 bridge, appears to have moved downstream, probably as a result of flood flows. The riffle is formed by gravel deposits constricting the channel. The riffle is about 1,950 ft long and 10 to 300 feet wide and provided about 420,000 square feet of spawning area in 1982. The substrate is coarse gravel and cobbles.

The lower third of Mathews Riffle is now a glide. The right bank point bar on the upper third of the riffle shows some erosion.

5.1.1.6 Aleck Riffle. Aleck riffle is small, only about 375 feet long and 150 feet wide for about 56,250 square feet of spawning area in 1982. The riffle is caused by constriction in the channel from a relict point bar feature that pre-dates the Oroville facilities. The riffle surface is armored with coarse cobbles and gravel. Subsurface gravel would provide excellent spawning gravel.

The upper riffle has remained the same. At the lower end, the right bank has eroded and the riffle is now a glide.

5.1.1.7 Great Western Riffle. Great Western is also a small riffle, about 200 feet wide and 200 feet long, and providing about 52,500 square feet of spawning area in 1982. The riffle is about 750 feet below the inlet of the abandoned Great Western canal. The riffle area surface is predominately cobbles with some gravel.

The riffle has been washed out and no longer exists. It is now part of a long pool.

5.1.1.8 Robinson Riffle. Robinson riffle is adjacent to Robinson pond, an abandoned gravel mining area. At present, the levee separating the pond from the riffle has been breached, resulting in substantially reduced streamflow over the riffle area. The channel here is relatively unstable. In 1982, the flow was split around an island, with the left channel providing about 125,000 square feet of spawning area and the right channel providing 47,000. The substrate varies from cobbles and boulders at the upstream end and coarse gravel and cobbles at the downstream end.

At Robinson Riffle the original right and left channels have become one riffle and the top has moved downstream approximately 450 feet. A left channel and riffle now exists where flows have breached the levee between the river and Robinson Pond. Part of the flow now flows through the pond itself. Another small riffle (upper Robinson) now extends diagonally from the right bank gravel bar to the gravel bar above Robinson Pond.

5.1.1.9 Steep Riffle. Steep is a very small riffle, providing only about 4,100 square feet in 1982. The riffle is located about 1,000 feet below Robinson, and above the return flow from Robinson pond. Substrate composition is mostly large gravel and cobbles.

Steep Riffle has moved downstream and is now a split channel. The majority of the water now flows through the gravel bar on the right bank. The small riffle downstream no longer exists.

5.1.1.10 Weir Riffle. Weir riffle is below the Robinson pond outflow. The riffle is 1,250 feet long and 125 feet wide, for about 156,000 feet of spawning area in 1982. The riffle is covered with coarse gravel and cobbles.

Weir Riffle is now a glide.

5.1.1.11 Gateway Riffle. Gateway is the last of the Low Flow Channel riffles and is located about 2000 feet above the Thermalito outfall. The riffle is long as it drapes around the right side of an island. The riffle measures about 1,200 feet long by 75 feet wide, for a total area of about 90,000 feet of spawning area. Substrate is coarse gravel with cobbles. A high flow channel is on the left side of the channel. This could be developed for additional habitat.

Eye Riffle now exists where no riffle was identified on the 1982 Atlas above Gateway. The upper reach of Gateway Riffle is now a glide with the riffle area only occupying the central reach.

5.1.1.12 Sutter Buttes Riffle. This riffle is the first of the High Flow Reach riffles and is located about 1,300 feet downstream of the Thermalito Afterbay outfall. The riffle provided 282,000 square feet of spawning area in 1982. Sutter Buttes riffle is at the head of a long section of split-channel flow. The rest of the double channels are low gradient and flow velocities are too low for spawning.

There have been no significant changes on this riffle since 1982.

5.1.1.13 Conveyor Belt Riffle. This small riffle covered about 38,000 square feet in 1982. The two channels that split at Sutter Buttes riffle about one mile upstream converge directly above the beginning of the riffle. Cobbles and boulders line most of the riffle.

Conveyor Belt Riffle has shifted to the right side of the channel where the river has eroded into the right bank just below the mid channel island/bar. The riffle itself extends diagonally from the tip of mid channel island to the right bank approximately 350 feet downstream. In 1982 the riffle spanned the width of the channel where the two channels came together just downstream of the left channel.

5.1.1.14 Hour Riffle. Hour riffle covered about 187,500 square feet in 1982. The riffle is covered by coarse gravel and cobbles. The main spawning area is downstream of a gravel island. The surface is mostly cobbles and coarse gravel.

The riffled areas at Hour Riffle have shifted some. In the upper reach where the river cuts across a mid channel bar in three places the riffled area has increases in the central cutoff forming a wider and longer riffle here and as gotten smaller at the lower cut over. A glide now exist where it use to be a riffle on the lower reach.

There is a section of riffle below Hour riffle, referred to as Lower Hour riffle. The upper part of this riffle has shifted downstream. Channel width has increased on the right bank. The mid channel gravel bar now extends across the left channel.

5.1.1.15 Keister Riffle. This site is 1,900 feet long by about 300 feet wide for a total of about 570,000 square feet of spawning habitat in 1982. The riffle is formed at the head of a point bar. The upper part generally has velocities that are adequate but velocities in the lower two-thirds are too low. The substrate composition is predominately coarse gravel to cobble. The point bar has gravel that is suitable for salmon spawning and could be moved to the riffle area.

The upper riffle reach has widened where it has formed across a mid-channel bar of which the lower quarter still exists. The lower riffle area is no longer a riffle.

5.1.1.16 Goose Riffle. Goose riffle had about 145,000 square feet of spawning area in 1982. The surface consists of coarse gravel and cobbles. Goose is at the head of a large island. The left channel is an overflow channel that could be developed into a side channel.

The head of Goose Riffle has moved downstream and the lower part of this riffle has widened toward the left bank.

5.1.1.17 Big Riffle. Big riffle contained 255,000 square feet of spawning in 1982. This riffle was once the site of intensive spawning. The armored riffle surface, low velocities and deeper flow creates marginal spawning habitat.

The head of big Riffle has moved upstream approximately 200 feet. The central part of this riffle is now a glide and the lower section a run. The adjacent gravel bar on the right bank has accreted toward the center of the riffle.

5.1.1.18 MacFarland Riffle. This riffle is large, with 550,000 square feet of spawning habitat in 1982. It is 2,000 feet long and 280 feet wide. MacFarland is on a meander bend with a large point bar. Substrate tends to vary, and ranges from coarse gravel to cobbles in the upper part to medium gravel in the lower part. Some of the gravel on the riffle is derived from bank erosion. Much of the lower part of the riffle does not have adequate spawning velocities.

The head of Macfarland Riffle moved upstream 250 feet. The central part is now a glide and has moved right approximately 450 feet. The lower riffle has moved approximately 200 feet to the left and then cuts back to the original channel.

5.1.1.19 Gridley Riffle. Gridley riffle is located about one mile below the Gridley bridge. It had an area of about 332,000 square feet in 1982. The riffle area is complex, with multiple channels, islands, point bars, bank erosion, and meandering. The substrate is predominantly medium to coarse gravel, and the water velocity and depth are adequate throughout most of the riffle area. Spawning, eggs survival, and rearing are limited by unfavorable water quality and temperature at certain times of the year.

At the head of Gridley Riffle three riffles existed where channels cut through a gravel bar. Now there are two with the one farthest upstream filled in. The channel on the right has widened and the riffle head moving downstream approximately 500 feet. The remainder of the riffle is the same.

Junkyard riffle is a smaller riffle located between Gridley and Herringer. Junkyard Riffle has also remained about the same. The main change is the orientation. The riffle on the left main channel is now a run.

5.1.1.20 Herringer Riffle. Herringer is the last of the salmon spawning riffles. Areas below contain gravel too fine for spawning and temperatures are generally too high for successful egg incubation. Most of the spawning occurs along a side channel on the right side of the channel. Some spawning occurs below Herringer, but it is very limited.

The upper part of Herringer riffle has remained relatively unchanged with the exception of the deposition of gravels on the mid channel bar of the right channel and a slightly different orientation of the riffle where the right channel cuts over to the left.

At Herringer Riffle, the river used to flow around mid channel bar. The right channel is now closed off at the upstream end from gravel bar development and the right channel is now a backwater. On the left channel, a smaller mid-channel bar has been reduced in size and the riffle area has increased to the right. At the lower end of Herringer Riffle (upstream of the downstream end of the prior right channel) the channel and riffle have widened and the point bar on the right bank has filled in a pre-existing side channel.

5.2 VOLUMETRIC (BULK) GRAVEL SAMPLING

Particle size distribution in gravel and cobble-bed streams is commonly measured with two different methods:

1) <u>Volumetric (bulk) sampling -</u> samples a pre-selected sediment volume from a predefined sedimentary layer, sieved, and weighed (Photo 5.2-1).

2) <u>Surface sampling (Wolman counts) -</u> samples a pre-selected number of surface particles from a predefined sampling area. The particle size is measured with a ruler and recorded

Bulk sampling is the collecting and sieving of gravel. Five commonly used methods are:

1) <u>Freeze core method -</u> The freeze core method is slow and expensive and does not produce a large enough sample in coarse gravel substrates to be statistically representative.

2) <u>Excavated core (McNeil Sampling) –</u> McNeil sampling is effective in fine gravel substrate, but the core barrel is difficult to drive into coarse gravel and cobbly gravel found in the study area. Sample size is generally too small to be statistically significant.

3) <u>Clamshells and scoops-</u> Clamshells and scoops are generally designed for use in sand or finer sediments and take samples limited to a few pounds. In coarser sediment, the fines generally wash out before the sample is retrieved.

Photo 5.2-1. Bulk Sampling at Aleck Riffle.

4) Sampling by shovel- Grost et al (1991) compared the freeze core, excavated core and shovel methods for sample composition, cost and field efficiency. The methods were field-tested on substrate consisting primarily of materials smaller than 10 cm (4 inches) in diameter. Water depths ranged from 6 to 40 centimeters (2.4 to 16 inches), and mean water velocities ranged from 20 to 80 centimeters per second (0.6 to 2.6 feet per second). Test results indicated no significant differences between the excavated core and shovel samples for any size-fraction of particles.

Grost et al (1991) concluded that a shovel is a viable alternative to an excavated core sampler for sampling in streams less than 1.3 feet deep with water velocities less than 2.6 feet per second and a stream bed consisting primarily of material smaller than 4 inches in diameter. They considered shovel sampling especially attractive for sampling in remote areas, in coarse substrates, or when sampling budgets are limited.

5) Sampling by shovel with a stilling well- A stilling well used with standard shovel was concluded by Hames et al to be an adequate substitute to the McNeil Sampler and that

there were no statistical differences between the methods in mean percent fine sediment or geometric fine particle size between the two methods. There were significant statistical differences in these categories using the standard shovel method. The percentage of fines was biased (low) in comparison to the McNeil samples and due to the large amount of variation.

The samples collected in 1982 and 1996 used the shovel method, and in 2002-2003 the shovel method along with stilling well was used. The stilling well was made from a 30" diameter, 2 foot high corrugated pipe. The shovel with stilling well method was used due to the ease of collecting samples with large clast size.

Determining particle size distribution and spawning gravel quality generally begins with sieve analysis. The sieving determines the grading of gravel, or the distribution of particles into standard size groups based on sieve mesh openings. Dimensions are recorded in mesh size units for smaller fractions and English units for coarser fractions (see unit conversion on inside of rear cover).

Conforming to the Unified Soil Classification System (USCS), fines are defined as particles passing a number 200 mesh sieve (0.074 mm). Coarse grains are larger than a number 200. Coarse grains are divided into, in ascending order, sand, gravel, and cobbles. Cobbles range from 3 inches to 10 inches in diameter. Gravel ranges from a number 4 sieve (4.75 mm) to 3 inches. The USCS defines sand as smaller than a number 4 sieve and larger than a number 200 sieve (0.074 mm).

Fines are of three types: silt, clay, and organic soils. Size distinctions are not made between silt and clay in the USCS but are differentiated by low (silt) or high (clay) plasticity.

The sieving splits the sample into size fractions which are tabulated or plotted as histograms or gradation curves.

The field sieve dimensions are two feet square with openings ranging from three inch to No. 4 mesh. Particles between three and six inches and particles larger than six inches were separated by hand using a ruler and weighed separately. The size and weight of all the cobbles greater than six inches were recorded with the largest particle used to estimate the required sample size. The field sieves were placed above a large plastic tray to collect and settle material smaller than the No. 4 sieve for laboratory analysis. A five-gallon bucket was used to carry water for washing the material through the sieves. Material retained on each sieve was weighed in a bucket on a hanging scale with the weight being recorded to the closest 1/8 pound.

Particles passing through the No. 4 mesh sieve were bagged and subsequently air dried at the office. After drying the sample was weighed and split by quartering method to obtain a representative sample in the 6 to 12 pound range for laboratory sieving.

Laboratory sieves ranged from No. 4 mesh to No. 200 mesh. The representative sample was then sieved with a mechanical shaker in 1 to 2 pound runs for 15 minutes each. The sample weight was adjusted to represent the full sample weight. Material retained on each sieve was weighed on a balance to the nearest 0.01 lbs.

5.2.1 Armored and Sub-surface Layers

Volumetric samples are three-dimensional and may be taken from various strata of the sediment column: the armor layer, the sub-armor and subsurface sediment, and a combined sample. The surface sediment, which has two-dimensional properties, cannot be sampled volumetrically.

Several mechanisms have been proposed to explain the cause of surface coarsening and the development of an armor layer. These include winnowing of surface fines, selective deposition of large particles, and increased availability of coarse surface particles as part of equal mobility transport. A difference between the particle-size distribution of surface and subsurface layer can also be caused by infiltration of fines into an open framework of subsurface gravel. Armored layers are poorly developed in streams with large sediment supply or in well sorted deposits.

Samples of the armor layer are used to characterize the streambed for many purposes including streambed monitoring and sediment transport analysis. The degree of armoring can be determined by comparing the particle-size distribution or the D_{50} of the armor layer with the D_{50} particle size of the subarmor sediment. The larger the armoring ratio, the larger is the degree of armoring. A change in the degree of armoring is used as an indication of a change in sediment supply or in flow regime.

The thickness of the armor layer is commonly described as extending from the bed surface plane down to the bottom side of the largest or a frequently occurring large surface particle size. A sample of the armor layer should extend over the entire thickness of the armor layer. If the sample is not sufficiently deep, it misses the fine particles under the coarse surface particles and produces a size distribution that is too coarse. An armor-layer sample that extends too deeply into the bed includes subsurface sediment which is finer than the armor layer and thus produces a sample that is too fine.

In order to sample the strata accurately, the thickness of the armor and subarmor layers need to be known. One possible way to obtain this information is to dig a pilot pit and examine the vertical extent of the respective strata. This approach is a labor and time intensive undertaking and is impeded by the fact that the thickness of sedimentary layers is spatially variable, which would require multiple pits. In order to avoid this procedure (which should not be completely dismissed), and considering the fact that the thickness of the armor- and subarmor-layer increases with the general coarseness of the surface sediment, several suggestions have been proposed to predict the thickness of the armor layer. All procedures are based on some characteristic of large surface particles. Armor thickness is approximated by:

- the c-axis of the largest particle (Ettema 1984), or the b-axis of the largest particle size (Diplas 1992 a);
- 2 times the b-axis of the D_{90} surface particle size (Simons and Sentürk 1992, p.654),
- the embedded depth of the reach-average dominant particle size, and the
- embedded depth of the local maximum particle size.

The five prediction criteria listed above result in somewhat different armor-layer depths when applied to the same deposit.

The criterion of two times the D90 particle size b-axis length also predicts a relatively thick
armor layer. Sampling the armor layer to a large depth risks including subarmor sediment in the armor sample. Mixing armor and subarmor sediment should be avoided when comparing the sediment size of the two strata because contamination makes a difference between the armor and subarmor layer less detectable.

All the samples collected between 1982 and 2003 used the b-axis length of the largest sample particle as a criterion for the depth of the armor layer.

5.2.2 Sample Size

Sample standards have been established by many organizations for numerous purposes. Most are inconsistent, established for different sizes, or for different purposes

Criteria established by Church et al (1987) were used to determine sample size in kilograms (2.204 pounds equal one kilogram). The criteria show the relation between the required sample quantity and the largest particle b-axis length. The ISO low precision standard is based on the sampling of sand and fine gravel with resultant reasonable sample sizes. However, for samples with largest stones in the range of 7 to 9 inches that are typical of the coarsest riffles on the Feather River, sample sizes would range from 2000 to 3500 pounds.

Church et al (1987) recommends the use of lower precision for samples with larger clasts. He recommends the use of the 1 percent precision line to 128 millimeters (5 inches) and the 5 percent line for samples with larger clasts. The latter results in a sample size of about 700 pounds for a 9-inch particle.

Church et al (1987) also state that in fishery studies where the proportion of fines are used to measure suitability, the samples may be truncated by not considering particles larger than 64 millimeters (2.5 inches). This can be done since the few larger particles will not influence the habitat issue materially. This imposes a sample size requirement of 80 pounds to meet the one percent and about 770 pounds to meet the 0.1 percent criteria in Figure 6. We did not adopt this methodology because the samples would not be comparable to 1982 and 1996 samples.

The criteria are informal and no statistical assumptions are made. Sampling precision for the larger particles is low, probably in the plus or minus 5 percent range, but high enough to make spawning gravel quality determinations. Meeting ISO or higher precision standards for the 6- to 9-inch diameter fraction would require heavy equipment and production sieves.

DWR collected gravel samples averaging between 500 to 700 pounds. The large samples were necessary because of the large particle size. Many riffles contained a substantial portion of cobbles. This sample size generally falls between the 1 and 5 percent precision lines.

The sample area surface dimension was 5-6 foot circle. The surface layer was collected and sieved separately from the subsurface layer. The surface layer sampling depth is defined by the diameter of the largest particle, generally ranging from four to seven inches. The maximum sampling depth of the subsurface layer was determined by the required sampling weight and typically extended to a depth of 12 to 16 inches by 30 inches in diameter.

In 2002-2003, at riffles that had distinctive dune and trough sequences two bulk samples were taken, one for each feature. The same size of surface sample was collected at each feature, but only half the subsurface was collected which was later statistically treated as one sample.

5.2.3 Sampling Equipment and Procedure

The sieving splits the sample into size fractions which are tabulated or plotted as histograms or gradation curves. Table 5.2-1 lists the sieve sizes used by DWR in the

1982, 1996 and 2003 sampling programs.

Table 5.2-1. Sieve Sizes used in 1982, 1996, 2003 Bulk Sampling

Sieve Size (mesh number)	Sieve Size (inches)	Sieve Size (mm)	1982 Bulk Sampling*	1996 Bulk Sampling	2003 Bulk Sampling
Hand Measured	6.00		**	X	X
Field Sieves					
	3.000	76.2	X	X	X
	1.500	38.1		X	X
	1	25.4	X		
	0.750	19.05		X	X
	.5	12.7	X		
	0.375	9.525		X	X
#4	0.187	4.75		X	X
	.16		X		
Laboratory Sieves					
#8	0.0937	2.36		X	X
#16	0.0469	1.18		X	X
#30	0.0232	0.589		X	X
	0.015	0.381	X		
#50	0.0117	0.3		X	X
#100	0.0059	0.15		X	X
#200	0.0029	0.074		X	X

*Sizes obtained from Table 10, DWR 1982.
**Maximum size was recorded above 6 inches but weight was not recorded.

The equipment used by DWR-ND to perform bulk gravel sampling included a set of Sieves (Rocker Box style) (Photo 5.2-2), a metric ruler, sawhorses and boards for support, buckets, shovels, picks, tarps, tubs, rebar, a 30-inch culvert, and a tripod with a hanging scale. The equipment setup is shown in Photo 5.2-3

Photo 5.2-2. Field Set of Gravel Sieves (scale in foreground is 18-inches long)

Photo 5.2-3. Bulk Gravel Sieves Setup at Hour Riffle

A GPS was used to locate the bulk gravel sample in 2002 and 2003. If the channel geomorphology changed significantly, then additional more representative sampling locations were identified. The 30" culvert is placed at the marked sampling location. A fence post is pounded in through the welded handle on the upstream side of the cylinder to hold it against the current. The tripod is set to support the scale and weighing bucket. The screens are stacked and supported on sawhorses and boards, with a tarp to collect and funnel the wash water and finer sediment into a bucket and a plastic trough.

The surface gravel is removed from inside the stilling well and one shovel width around the outside of the well. By doing this it creates a larger surface sample from a five to six foot diameter area and helps prevent surface gravel from caving under the stilling well when the subsurface sample is collected.

Five gallon buckets of gravel are dumped onto stacked sieves and washed with rinse water, working the gravel through the successive sieve diameters.

Rocks with B axis greater than six inches in diameter are pulled from the top sieve, rinsed in the rinse bucket, allowed to drain in perforated weighing bucket, weighed and the weight recorded. The length of the largest particle's b-axis is also recorded. Gravel retained on each sieve is then weighed.

The sediment in the trough is allowed to settle, and the water is drained. The fines are then bagged for laboratory analysis.

5.2.4 Laboratory Sampling Equipment and Procedure

Particles finer than the No. 4 mesh sieve were bagged and subsequently air dried at the office. After drying, the sample was weighed and split by the quartering method to obtain a representative sample in the 6 to 12 pound range.

Laboratory sieves ranged from No. 4 mesh to No. 200 mesh. The representative sample was sieved with a mechanical shaker in 1 to 2 pound runs for 15 minutes each (Photo 5.2.4). The sample weight was adjusted to represent the full sample weight. Material retained on each sieve was weighed on a balance to the nearest 0.01 lbs.

Photo 5.2-4. Stacked Sieves for Laboratory Sieving

5.2.5 Sampling Results

Spawning gravel quality is affected by scour below dams. Since the 1909-1911 topographic surveys by the USACE, the Lower Feather River has been degrading. Post dam surveys done by the USGS (1972) and this study show that the river is continuing to degrade, but at a slower rate. Degradation generally washes away the finer bed material and leaves a coarser lag deposit generally referred to as an armor layer.

Spawning gravel quality investigations done by DWR in 1982 and 1996 show that the gravels on Feather River riffles are becoming coarser. The purpose of this Task report is to assess and evaluate changes in spawning gravel quality.

Bulk and surface sampling were done in the study reach by DWR (1982) for the Feather River Spawning Gravel Baseline Study. Twenty bulk samples and 176 surface samples were taken at the head of point bars. Since 1982, however, probably over 10,000 cubic yards of gravel have been placed in the river at some sites. The gravel placement adds a layer of confusion to trend analysis and to comparison of 1982, 1996, and 2002-03 surface and bulk samples.

We compared the statistical parameters of the surface Wolman samples and bulk samples for 1982, 1996 and 2002-03. The most marked trend is the continued coarsening of the gravel in the upper five riffles of the study reach even after the periodic importation and placement of spawning size gravel.

Below the Afterbay river outlet, surface and bulk sampling shows that most riffle sites have gravel that meets spawning criteria. Water flow and depth factors must play a larger role in site preference in this river reach.

Twenty bulk samples were taken from the Hatchery Riffle at River Mile 66.0 to Junkyard Riffle at River Mile 48.7.

Mechanical analysis results are plotted on semi-logarithmic graphs, and are referred to as gradation curves or mechanical analysis graph. Gradation curves graphically present the percentage of particles retained and passing through specific sieve apertures.

Along the X-axis, mesh numbers and sieve aperture sizes are arranged logarithmically. The arithmetic Y-axis is divided into percent coarser by weight on the right side of the graph and percent finer by weight on the left side. The bulk samples were analyzed in three categories: surface, subsurface, and combined surface and subsurface. Appendix A contains gradation curves for all sampled riffles.

A gradation curve shows the grading characteristics of a sample. A very steep curve, with no tail, indicates a poorly graded, relatively uniform sample with a small range of particle sizes. Conversely, a gentle curve indicates a well graded sample with a wide range of particle sizes. The surface, subsurface, and combined gradation curves are in Appendix A.

The shaded area on the graph shows the range in size distribution normally associated with quality spawning gravel. Most of the samples at least partially fall outside on the coarse side of this normal range. Two problems exist with the coarse gravel. First, the adult spawners may not be able to excavate riffles with a large amount of cobbles. Second, the eggs may wash out of the gravel because of the large intragravel pore spaces.

The plot of the combined curve is the most important indicator of suitability because it represents the entire composition of the gravel used by the salmon.

The plot of the surface sample is important in coarse substrates because it provides an indicator of armoring and the ability of the salmon to excavate the river bed.

Sample statistics are useful for comparing individual samples, plotting trends, and correlating with Wolman surface samples. Bulk sample statistics, including aspects of central tendency such as geometric mean diameter (D_g), standard deviation, D_{95}, D_{84}, D_{75}, D_{50}, D_{25}, D_{16}, D_5, skewness and kurtosis are useful for analyzing and comparing bulk samples. The statistical parameters were graphed to show both spatial and time related changes.

Several statistical parameters can be determined from the cumulative gradation curves. The standard deviation can be read directly from the curve as the phi values at D_{84}-D_{50} or D_{50}-D_{16}. The standard deviation is a measure of sediment sorting (Folk and Ward 1957). A well sorted sediment has particles of one size, and poorly sorted sediment has a wide distribution of grain sizes. A perfectly sorted sediment has a standard deviation of 1.

The D_g is useful because it can be manipulated algebraically. For example, the mean particle size of several combined samples is equal to the average of the means of those samples.

These dimensions are based on standard deviation increments: the D_{84} and D_{16} dimensions fall one standard deviation on either side of the median (D_{50}) and the D_{95} and D_5 dimensions fall two standard deviations on either side of the median.

Skewness is a measure of symmetry, or the degree of deviation from a normal distribution. The relative skewness can be estimated by comparing the D_{84} minus the D_{50} to D_{50} minus D_{16}. The greater the difference between the two values, the greater the degree of skewness. Skewness was calculated using the method of Warren (1974). Negative values indicate coarsely skewed, and positive values indicate finely skewed samples.

Kurtosis is a measure of the concentration of particles about the mean diameter, or the peakedness (Folk and Ward 1957).

Table 5.2-2 shows the statistical parameters for the 2002 to 2003 gravel sampling.

Table 5.2-3 shows the gravel sampling statistics for the 1996 and Table 5.2-4 shows the gravel sampling statistics for the 1982.

Figure 5.2-1 shows a comparison of bulk surface gravel D_{50} for the three sampling periods. Surface samples are skimmed from the surface and do not include the material below the armor layer. The trend lines show a general fining in the downstream direction, but a temporal coarsening between 1982 and 2002-03. The 2002-03 data also appears to have a larger degree of variation, with D_{50}s ranging from 50 to 175 mm (2.0 to 6.9 in) in the Low Flow Reach and 25 to 90 mm (1.0 to 3.5 in) in the High Flow Reach. The trend lines suggest an average Low Flow Reach D_{50} of about 105 mm (4.1 in) in 2002-03, 80 mm (3.1 in) in 1996, and 65 mm (2.6 in) in 1982.

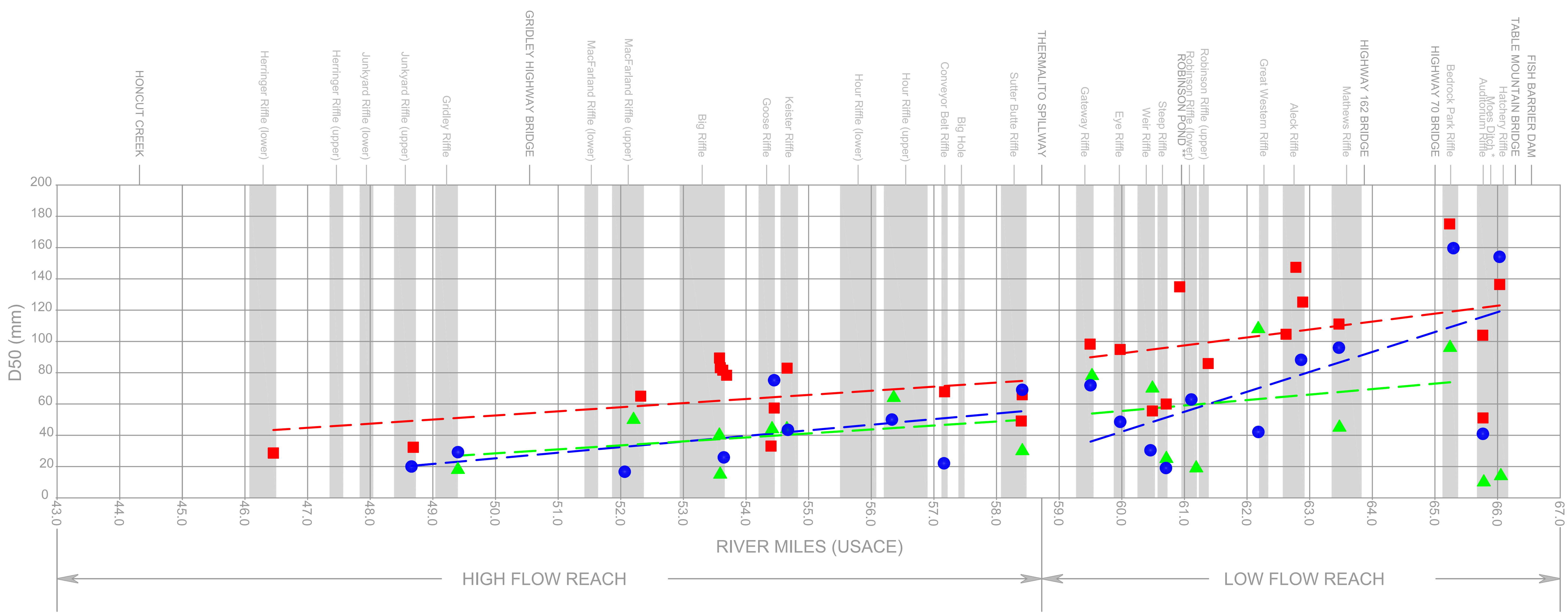
Similar numbers for the High Flow Reach D_{50}s are 55 mm (2.2 in) in 2002-03, and 35 mm (1.4 in) for 1996 and 1982.

Figure 5.2-2 shows a similar graph for the geometric means Dg. The Dg averages about 85 mm (3.3 in) in 2002-03 in the Low Flow Reach, and about 60 mm (2.4 in) in 1996 and 1982. The High Flow Reach averages 40 mm (1.6 in) in 2002-03 and 20 mm (0.8 in) in 1982 and 1996.

Figure 5.2-3 shows the D_{50} for the subsurface gravel sampling. The subsurface material is the material below the surface sample, and appears to be more consistent in size. The size variation also appears to be less dramatic in the downstream direction. The 2002-03 data shows a decrease from 30 mm (1.2 in) to 10 mm (0.4 in) from the top to the bottom of the study reach. Temporal changes are also small, with no clear change in diameter over the three sampling periods. The average D_{50} of the subsurface samples in the Low Flow reach is about 37 mm (1.5 in), the High Flow Reach is about 27 mm (1.1 in) and the study reach average is about 30 mm (1.2 in).

Figure 5.2-4 is a key figure that tells an important story. It shows the subsurface geometric mean diameter Dg. The trends are similar to the D_{50}s, but tend to be smaller. The geometric mean diameter is linked to gravel quality. A Dg of about 25 mm (1.0 in) is considered ideal. The graph suggests that much of the Low Flow Reach and about half of the High Flow Reach have subsurface gravel with adequate spawning gravel quality.

Figure 5.2-1. Bulk Surface Gravel Samples D_{50}s



LEGEND

2003 Bulk Sample D50

1996 Bulk Sample D50

1982 Bulk Sample D50

2003 Bulk Sample D50 -Linear Best Fit

1996 Bulk Sample D50 - Linear Best Fit

1982 Bulk Sample D50 - Linear Best Fit

NOTES

1) River miles based on USACE 1997 river center line. 0.0 = Feather River intersection with Sacramento River.

2) D50 - b-axis in millimeters.

3) * Spawning gravel injection at Moe's Ditch from 1971 to 1982, therefore, Linear Best Fits do not include these samples.

4) ** Robinson Pond - apparent gravel trap

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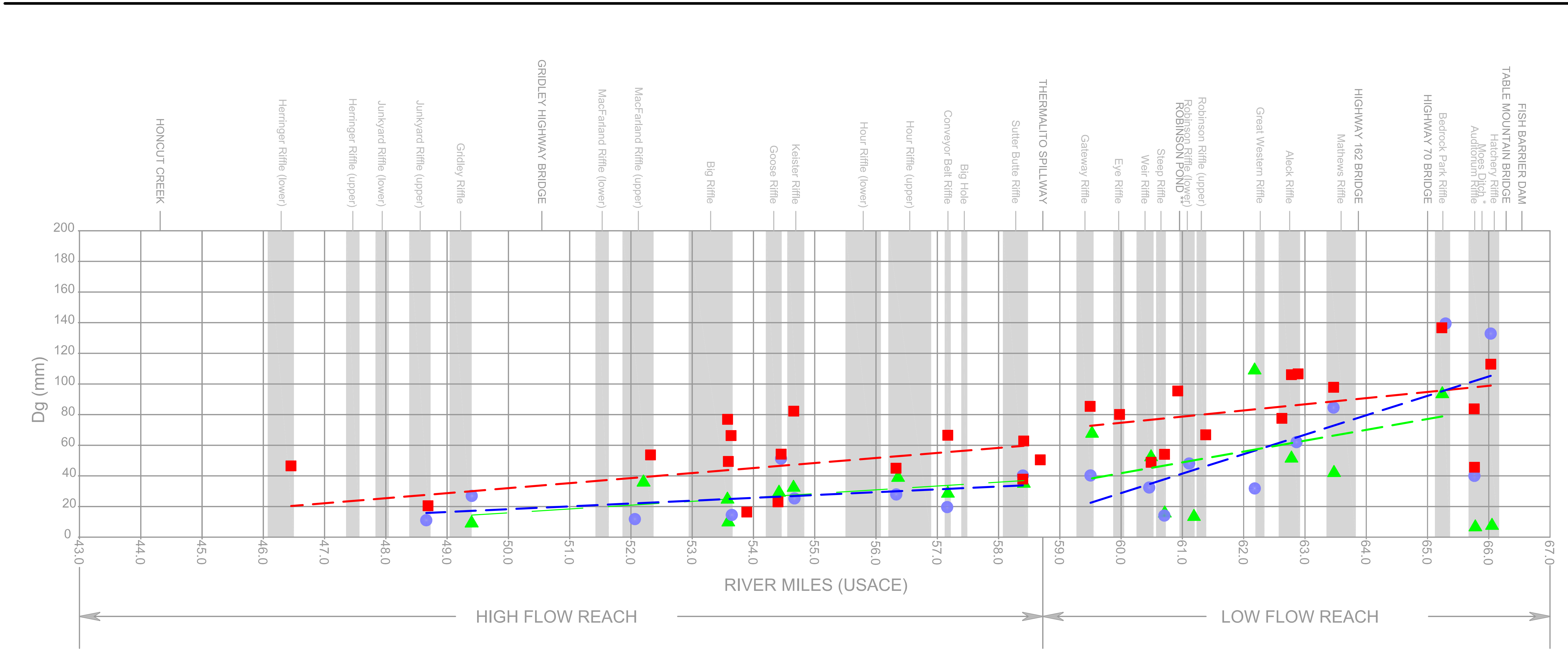
FIGURE 5.2-1
SP-G2 TASK 2

BULK SURFACE GRAVEL
SAMPLE D50s

Prepared by:	Date	Filename
GMG -- DWR	8/10/ 04	Figure 5.2-1.dwg

Figure 5.2-2. Bulk Gravel Sample Dgs



LEGEND

- 2003 Bulk Sample Dg
- 1996 Bulk Sample Dg
- 1982 Bulk Sample Dg
- 2003 Bulk Sample Dg -Linear Best Fit
- 1996 Bulk Sample Dg - Linear Best Fit
- 1982 Bulk Sample Dg - Linear Best Fit

NOTES

1) River miles based on USACE 1997 river center line. 0.0 = Feather River intersection with Sacramento River.
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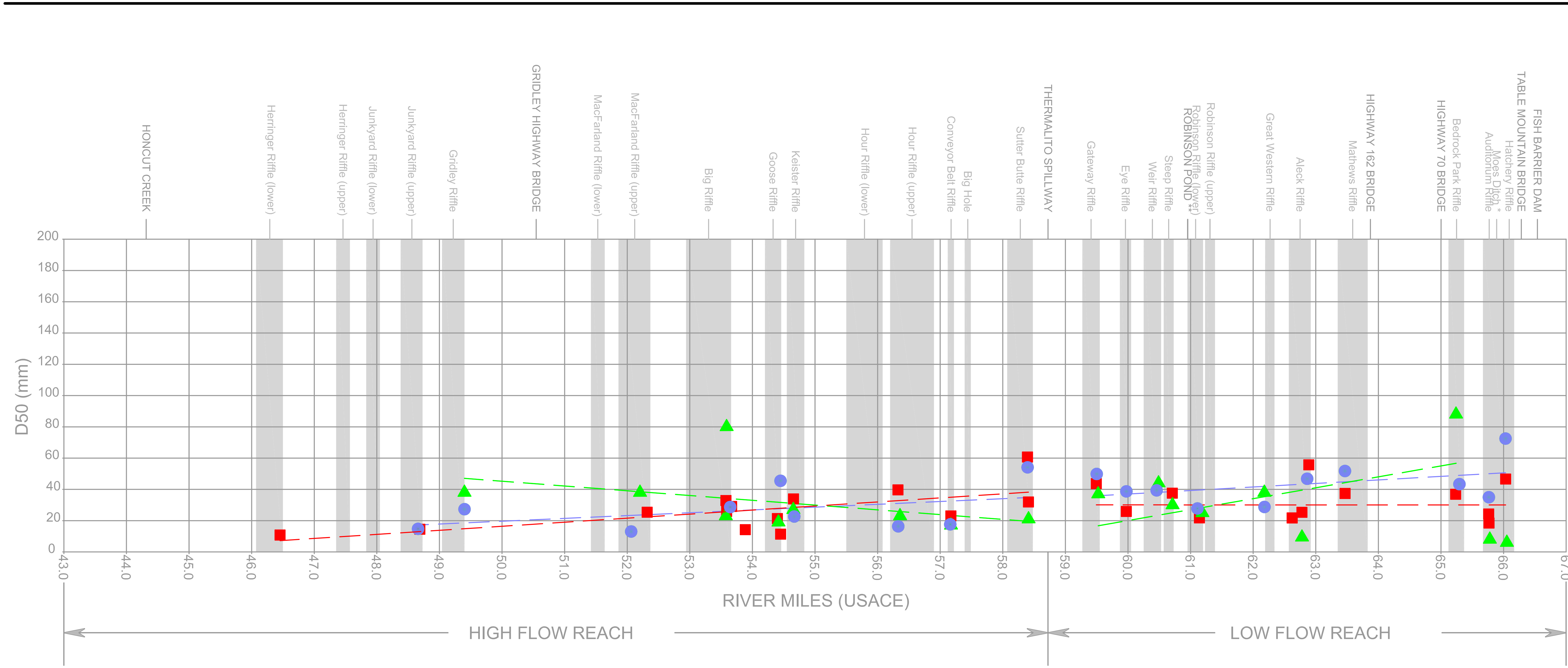
FIGURE 5.2-2
SP-G2 TASK 2

BULK SURFACE GRAVEL SAMPLES Dgs

Prepared by: GMG -- DWR	Date 8/10/ 04	Filename Figure 5.2-2.dwg

Figure 5.2-3. Bulk Gravel Subsurface Sample D_{50}s



LEGEND

■ 2003 Bulk Sample D50 -Linear Best Fit

● 1996 Bulk Sample D50 - Linear Best Fit

▲ 1982 Bulk Sample D50 - Linear Best Fit

— — — 2003 Bulk Sample D50 -Linear Best Fit

— — — 1996 Bulk Sample D50 - Linear Best Fit

— — — 1982 Bulk Sample D50 - Linear Best Fit

NOTES

1) River miles based on USACE 1997 river center line. 0.0 = Feather River intersection with Sacramento River.
2) D50 - b-axis in millimeters.
3) * Spawning gravel injection at Moe's Ditch from 1971 to 1982, therefore, Linear Best Fits do not include these samples.
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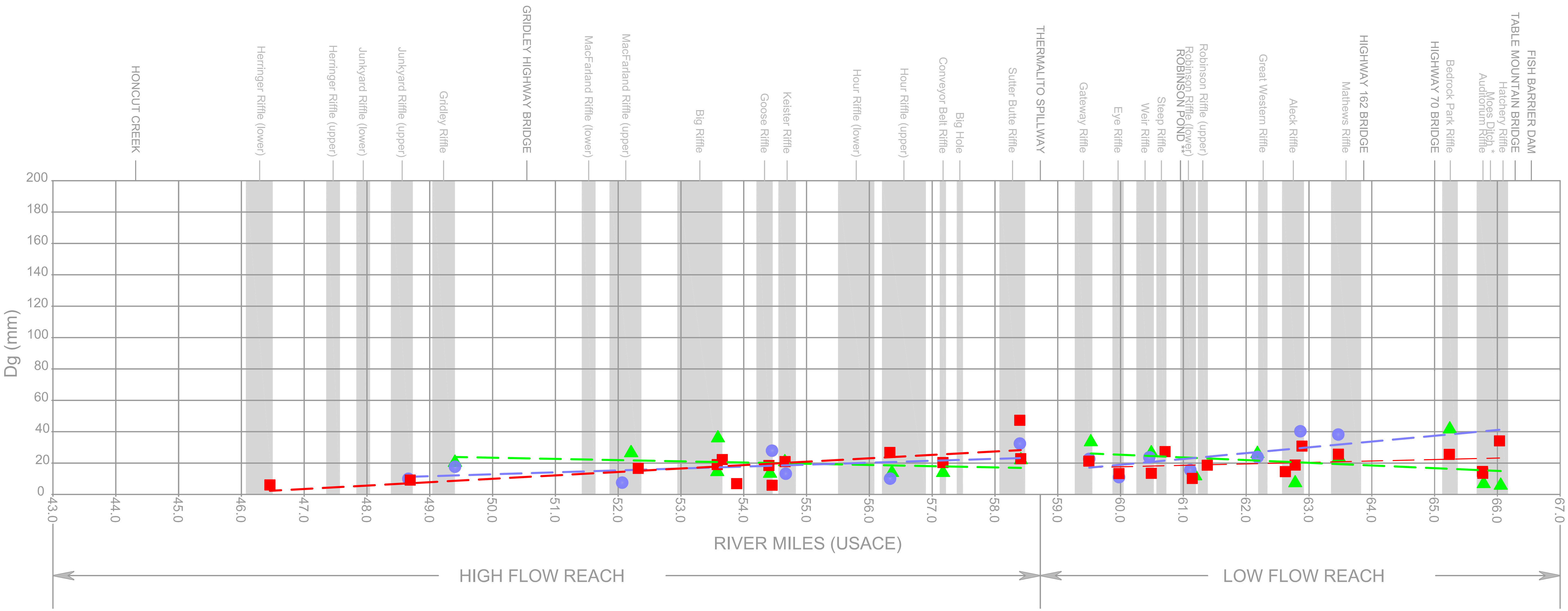
FIGURE 5.2-3
SP-G2 TASK 2

BULK SUBSURFACE
GRAVEL SAMPLES D50s

Prepared by: GMG -- DWR	Date 8/10/ 04	Filename Figure 5.2-3.dwg

Figure 5.2-4. Bulk Gravel Subsurface Sample Dgs



LEGEND

- 2003 Bulk Sample Dg
- 1996 Bulk Sample Dg
- 1982 Bulk Sample Dg
- 2003 Bulk Sample Dg -Linear Best Fit
- 1996 Bulk Sample Dg - Linear Best Fit
- 1982 Bulk Sample Dg - Linear Best Fit

NOTES

1) River miles based on USACE 1997 river center line. 0.0 = Feather River intersection with Sacramento River.
2) Dg - b-axis in millimeters.
3) * Spawning gravel injection at Moe's Ditch from 1971 to 1982, therefore, Linear Best Fits do not include these samples.
4) ** Robinson Pond - apparent gravel trap

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FIGURE 5.2-4
SP-G2 TASK 2

BULK SUBSURFACE
GRAVEL SAMPLES Dgs

Prepared by:	Date	Filename
JHM -- DWR	8/10/ 04	Figure 5.2-4.dwg

The sampling for this study also included sampling of dune and trough features in the riffle. A comparison of the surface sample D_{50}s is shown in Figure 5.2-5. In most instances, the troughs are coarser. The structures are probably related to Chinook salmon redd building. The mechanism for the development of the coarser trough may be the movement of the finer material from the redd to the tailspill, leaving a coarser lag deposit in the trough. Figure 5.2-6 is a similar figure for the Dg dune and trough comparison.

Figure 5.2-7 shows the subsurface sampling of dunes and troughs. It shows that the difference is slight between the dunes and troughs in the subsurface.

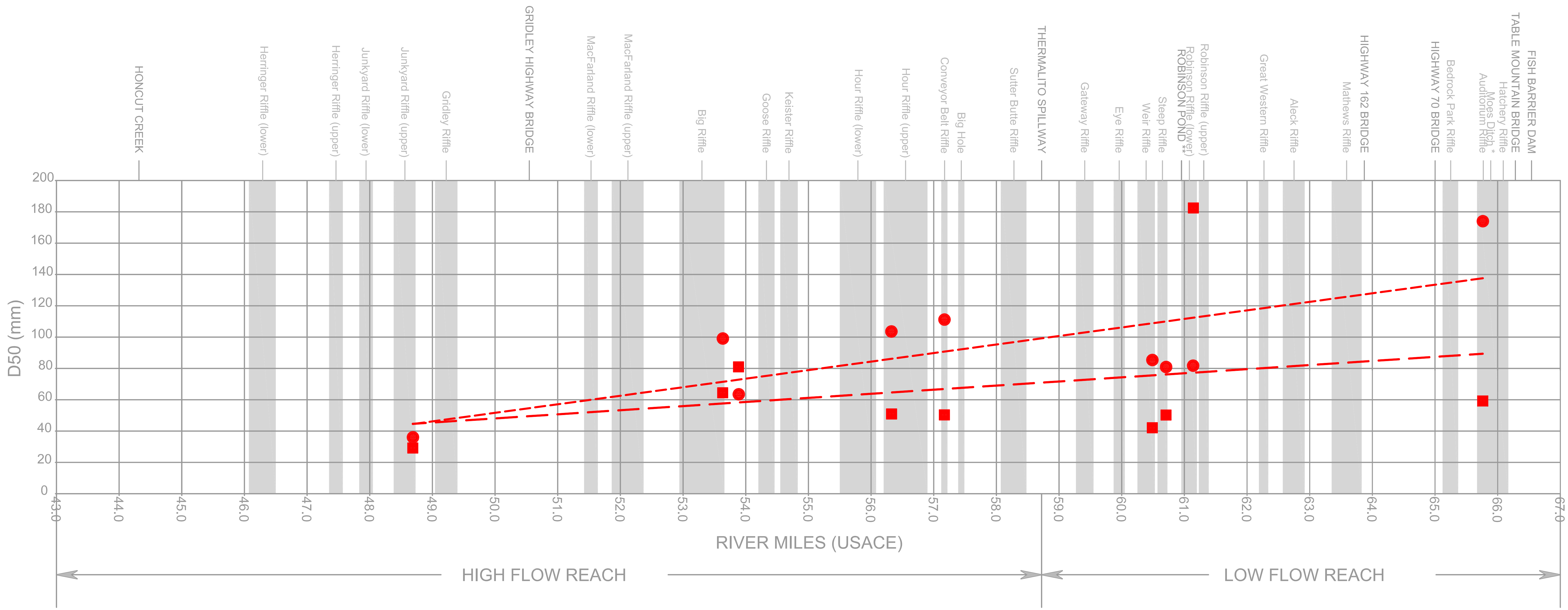
The subsurface dune and trough Dg comparison is shown in Figure 5.2-8. The amazing result of this sampling is uniformity in Dg. The linear best fit line shows only a small decrease in Dg over the study reach.

The sampling for this study also included sampling of dune and trough features in the riffle. A comparison of the surface sample D_{50}s is shown in Figure 5.2-5. In most instances, the troughs are coarser. The structures are probably related to Chinook salmon redd building. The mechanism for the development of the coarser trough may be the movement of the finer material from the redd to the tailspill, leaving a coarser lag deposit in the trough. Figure 5.2-6 is a similar figure for the Dg dune and trough comparison.

Figure 5.2-7 shows the subsurface sampling of dunes and troughs. It shows that the difference is slight between the dunes and troughs in the subsurface.

The subsurface dune and trough Dg comparison is shown in Figure 5.2-8. The amazing result of this sampling is uniformity in Dg. The linear best fit line shows only a small decrease in Dg over the study reach.

Figure 5.2-5. Bulk Gravel Surface D_{50} – Dune and Trough Comparison



LEGEND

- 2003 Dune D50
- 2003 Trough D50
- 2003 Dune D50 Linear Best Fit Line
- 2003 Trough D50 Linear Best Fit Line

NOTES

1) River miles based on USACE 1997 river center line. 0.0 = Feather River Intersection with Sacramento River.
2) * Spawning gravel injection at Moe's Ditch from 1971 to 1982, therfore Linear Best Fits do not include these samples.
3) ** Robinson Pond - apparent gravel trap

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FIGURE 5.2-5
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BULK SURFACE D50 - DUNE AND TROUGH COMPARISON

Prepared by: GMG -- DWR	Date 8/10/04	Filename Figure 5.2-5.dwg